THE SUPERVISION AND MAINTENANCE OF STEAM-RAISING PLANT

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THE SUPERVISION AND MAINTENANCE OF STEAM-RAISING PLANT

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PREFACE

THE post-war cost of fuel is gradually forcing power-plant owners to admit the imperative need for an organized system of boiler-house control. During the last few years a vast amount of work has been undertaken in the leading countries of the world with the object of introducing more economical methods in steam production. Such activities, however, are as yet confined mainly to the technical press, research institutions, select committees, and a few of the larger and more enterprising firms.

With many firms the fuel bill is the largest item in the expenditure account, and any scheme for reducing it is, therefore, worthy of the closest attention. Yet the average manager still regards the boiler house as a necessary evil rather than as a productive department in which air, water, and fuel are utilized as raw materials to make steam of a standard quality, and the problems of which are deserving of the same attention that is given to the remainder of the factory. The final product of this department is not so tangible as the concrete articles turned out by other departments; but in many factory processes the cost of the steam is greater than that of the ingredients used.

To deal with the scientific control of steam-raising plant, a new type of engineer is coming into being—namely, the combustion engineer or technical chemist, spoken of in the following pages as the "engineer-chemist." Some time must pass, however, before really qualified engineer-chemists will be available in any large numbers. It has been the author's aim to assist power-plant owners, managers, and engineers to operate steam-raising plants as efficiently as possible under existing conditions, and to indicate the type of service which will be rendered by the engineer-chemist in days to come.

The work is divided into two parts. The first part deals with the supervision or actual working of a plant, whilst the second explains the repairing and general overhauling of the component parts. The subject-matter has been divided on a plan which makes cross-reference as easy as possible. A reader, for example, who is specially interested in superheaters or other auxiliary appliances, the supervision of which is described in Chapters V., VI., and VII. in Part I., can readily turn to Chapters XIX. and XX. in Part II., where he will find what the author has to say on these same items from the point of view of maintenance.

Having in mind the practical man's need for a handy work of reference, the author has endeavoured to present all the information in the simplest possible form, and discussion of the theoretical side of the subject has been reduced to a minimum. For the same reason only such detail has been included, especially when describing instruments, as directly concerns the efficient working of steam-generating plant.

PREFACE

About half the illustrations have been especially prepared by the publishers from sketches submitted by the author, and the remainder are reproduced by kind permission of the firms whose products are illustrated. In selecting these latter illustrations very great care has been exercised to ensure that they fully illustrate the remarks in the text, and it will be noticed that many of the illustrations show additional points of interest referred to in chapters other than those in which they actually appear.

Throughout the book the author has been influenced by the fact that while it is the duty of the engineer in charge of a boiler plant to operate it at maximum efficiency and to effect all the improvements he can, he is not required to design new plant.

The author desires to express his indebtedness to the many firms mentioned in the book for supplying information and giving valuable assistance in reproducing illustrations of their appliances.

Thanks are due to Mr. Alwyne Meade, author of *Modern Gasworks Practice*, on whose suggestion the present work was undertaken. The author also wishes to acknowledge valuable assistance received from Mr. W. T. Colver in preparing the subject-matter for publication.

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PART I

SUPERVISION

THE SUPERVISION AND MAINTENANCE OF STEAM-RAISING PLANT

SECTION I.—WORKING THE POWER UNIT

CHAPTER I

ORGANIZATION

(a) *Introductory.*—The value of scientific control in order to ensure economical working is gradually being recognized. Modern business methods, together with the very keen competition that exists to-day, demand that the cost of manufacturing an article must be known from the time when the raw material enters the factory until the finished article is ready for the market. Very elaborate systems have been devised for the purpose of analyzing the cost of the various treatments which the raw material undergoes; and in the up-to-date factory these have been brought to such perfection that any inefficiency is immediately detected.

It is, therefore, all the more curious that, with very few exceptions, the control of production costs is limited to the manufacturing side of the factory. The manager of a factory, like every other specialist, has studied one particular subject, and by virtue of his ability has risen to high executive rank. He is proficient in his particular craft, and he will devote his entire energy to the production of soap, paper, cloth, or whatever his speciality may be, to the end that the product of his firm may be the most acceptable on the market.

Supposing every factory were supplied with power from some external source, the manager's problem, so far as power was concerned, would simply be to obtain the maximum production with minimum power consumption, and, in view of the proficiency of factory managers in their various crafts, a very high state of productive efficiency would exist in every industry. Unfortunately such a state of affairs does not, and in many cases cannot, exist, and by far the larger number of factories have their own power production plants.

Many factories are, of course, supplied with power from external sources—generally in the form of gas or electricity—with excellent results. Such establishments, however, fall into three special classes, as follows:

(i.) Very small factories for which so little power is required that a small electric motor or a gas engine will meet their requirements.

(ii.) Factories situated in localities where the ground rents are so high that it is cheaper to buy power from an external source than to occupy valuable space with a boiler plant.

(iii.) Factories near the centres of large towns. In these cases the expense of carting away ash, etc., must be reckoned in the gross cost of fuel, and as this item may amount to as much as 20 per cent. of the original price, a separate power plant is financially impracticable.

At the present time considerable attention is being paid to the possibilities of electrification on a large scale. Great electricity undertakings exist in almost every part of Great Britain, and a serious start has been made to supply the manufacturing areas with electrical energy, but it is doubtful whether complete reorganization of industry on the basis of electrification will ever be effected in a country which has so long been industrialized under other conditions.

Another very important point to be noted is that the production of electrical energy is not a national and therefore organized industry, with a uniform standard supply system, but is in the hands of a large number of private companies and municipal authorities working independently of each other. Direct consequences of this state of affairs may be seen in London, where the various supply systems are all different and a condition approaching chaos has been reached.

Finally, there are certain industries in which the amount of energy that is converted into power is a very small percentage of the energy utilized for heating, an example being the dyeing industry. Here the steam consumed in generating mechanical power is very small in comparison with that required for process work.

A very large number of industrial plants in Great Britain are situated on or very near to the important coalfields, and these, by entering into contracts for continuous supplies, can buy their coal at very favourable prices. As far as the important industries are concerned, it is, therefore, not likely that any radical change will take place, for some time to come, in the mode of power production. The boiler house will continue to supply the needs of the average factory.

In any case it will cost considerably less to make boiler houses as efficient as they should be than to erect super-power stations and lay miles of cable, and even if a gradual electrification should be put in hand, economy and efficiency in the old methods of power production would still be necessary during the interval between the present time and the date on which the whole country can be supplied with electricity.

Assuming, then, that there is no immediate prospect of greatly increased facilities for obtaining power from external sources, the capable manager of a modern plant must see that the same standards of efficiency are maintained in the production of internal power as in any other department of the factory. But until the boiler house ceases to be looked upon as a necessary evil, there will be little hope of improvement upon the conditions that prevail in the average factory to-day.

In view of the high prices of all fuels, and especially of coal, the waste that is allowed to go unchecked is appalling. No such waste would be tolerated for a single day on the manufacturing side. Why is it tolerated in the production of power? The answer is that we are only beginning to realize, in the light of recent developments, that the economical production of steam is just as scientific a business as the economical production of soap, paper, or cloth.

Every boiler house should be in charge of a skilled engineer who has studied the art of producing steam as thoroughly as the factory manager has studied his particular craft. Under present conditions the boiler house is generally looked after by the works engineer, who, as often as not, is only a mechanic by trade. This does not mean that the mechanic, generally a very old employee of the firm, is incompetent—far from it!—but he does not possess the specialized knowledge necessary to run the boiler house in the most economical manner. Again, if an engineer or mechanic has to divide his attention between the works and the boiler house, it is always the boiler house that receives the smaller share. Some machinery suddenly needs attention in the factory, and if the engineer happens to be superintending in the boiler house, he must leave his work to attend to the needs of the factory.

Very few owners realize what a boiler plant really is. The boiler plant is a productive department “ on its own,” where certain raw materials—air, water, and fuel—are treated in such a manner that they produce a standard article—namely, steam of a predetermined quality. Because the boiler pressure cannot be maintained, this predetermined quality is very often not supplied, and then, but not till then, the manufacturing side begins to manifest an interest in the power plant, though generally only in the form of complaints.

Many of the larger factory owners, however, who have studied the matter from a practical point of view, realize that it is useless to maintain strict observation over one part of a plant while allowing another part to function as best it can without expert attention.[1] Several of the model works in this country, whose products are known in every household, generate their own power in what may truly be termed “ model ” power houses, because they have found out that this is the correct procedure. The utilization of the raw materials, fuel, water, and air, is under constant observation by a skilled staff. Consequently, the finished product, steam of a certain pressure and temperature, is of uniform quality. Only a very small variation, within 2 per cent. of the standard, is permitted, with the result that the productive capacity of every department using steam for process work is known, and can be regulated to a nicety.

To achieve such results the production of steam must be in the hands of a skilled engineer, who has mastered his subject. A small number of such highly-trained specialists exists to-day, and their ranks are constantly increasing.

Most technical colleges have a separate department for fuel technology, where a fixed course of instruction may be followed. Specialists in this line of work have received various names, such as combustion engineer, steam specialist, and technical chemist, but these titles are all intended to convey the same meaning. In this book the term “ engineer-chemist ” will be used to describe this type of specialist.

The engineer-chemist must be a thoroughly practical man, and besides possessing a recognized diploma, awarded after three years' continuous study at a technical college, he should have served an apprenticeship of at least three years, the greater part of this having been spent in the making and repairing of boilers and auxiliary appliances. He must, in addition, be able to prove that he has had at least three years' practical experience in boiler-house work, and that he possesses an unerring knowledge of the combustion of fuels His function, when a fully-fledged engineer-chemist, will be to take complete charge of the production of power, and to operate this department in such a manner as to obtain the highest efficiency possible with the machinery at his disposal The engineer-chemist will probably be responsible not only for the efficient production of the steam which is used as steam for process work in the factory, but also for the production of mechanical energy, by which is meant the proper utilization of the steam in either reciprocating engines or turbines as the case may be

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[1] *Steam Power and Mill Work*, G. W. Sutcliffe.

With the latter item this book is not concerned, and for convenience it is assumed that all the steam generated passes through one main stop-valve situated at the entrance to the factory The engineer-chemist's duty under such conditions is to work his boilers, the auxiliary appliances such as superheaters, economizers, etc , and the subsidiary plant comprising feed-water treatment apparatus, coal handling plant, etc , so that the steam passing through the aforementioned stop-valve may always be:

1. Of the same pressure.
2. Of the same temperature, if superheated
3 As cheap as possible.

The more stages there are in the manufacture of a commodity the more difficult it is to fix the final selling price, and hence the greater the need for all-round scientific control. Electricity power stations might be quoted as an instance of direct conversion of the finished product of the boiler house into the final commodity as supplied to the consumer namely, electrical energy. It is, therefore, a comparatively simple matter to total the direct and indirect costs involved in the production, and to arrive at the selling price.

On the other hand, where the raw material undergoes many changes, as, for instance in the manufacture of soap, the matter is more complicated Take, for example, one ingredient fat This often comes to the soap works as industrial refuse, and is first melted down for purification. Then it is boiled many times and subjected to several other heat treatments, in addition to which it is pumped by steam pumps from one department to another. The cost of steam is thus seen to be an important factor in soap production.

In the dyeing industry, where the raw material is almost constantly in boiling liquid of one sort or another, so long as it remains in the works, the efficient management of the boiler house may make all the difference between a loss and a profit.

It is the duty of the engineer-chemist to compile statistics from week to week, so that the cost per unit of steam may be known and controlled. A unit of steam may be fixed at any magnitude, but in this book the unit quantity will be 10,000 pounds of steam of the required standard.

Few people realize the tremendous influence which cost of steam production has exercised upon international trade. Great Britain has been endowed by Nature with very large and valuable coal deposits. Formerly coal was very cheap, and the long period during which the price of coal was low has given rise, in the minds of most people, to an idea that coal is *common stuff*. The price of coal has not been at the high figure at which it stands to-day long enough to make us realize that the economical use of this now expensive raw material is a matter of urgent necessity. A casual glance into any vehicle taking away house refuse, with particular reference to unburnt fuel, commonly called cinders, will confirm this statement. Similar wastefulness characterizes the operation of most boiler plants.

Coal, in the minds of works engineers as of ordinary people, is simply there to be burnt, and with that the matter ends. Outside the gas-making industry little thought is given to the possibility of exploiting this rich mineral to its fullest extent by first subjecting it to such a process as low temperature carbonization, so as to extract from it valuable by-products in the form of oils, illuminating gas and artificial manure, before burning the “ semi-coke ” residue. This subject is again dealt with in the concluding chapter of the present work, and is mentioned here merely to indicate the commercial possibilities of scientific steam production.

The question immediately under consideration is the relation of steam production to manufacturing costs. A careful study of the steam-raising methods adopted in countries in which coal deposits are non-existent, or, if they exist, are inadequate in quality and extent, brings to light a mass of remarkable information. The inhabitants of such countries have been taught to place a very high value on coal, and have learnt their lesson well. Although in many instances manufacturers are charged double the price per ton paid by British owners, the cost of producing 10,000 pounds of steam of a given standard is very much less. The explanation is not to be found in superior boilers or apparatus, for British products deserve their world-wide reputation for excellence, and in several of the cases which have been investigated the plant was of British manufacture. Steam is produced cheaply under unfavourable conditions, because those responsible for its production have applied to their problem reliable methods of scientific control, together with personal interest and an almost loving care, that will always produce good results in whatever part of the world they may be applied.

There is no reason whatsoever why every boiler house should not be worked at the highest efficiency possible[1] with the quality of the coal burnt and the purity of the water used. Raising the efficiency of boiler houses, including those attached to electrical power stations, will only bring this department into line with the productive efficiency prevailing in other branches of industry.

Fig. 1 represents graphically the efficiency at which an average power unit can be worked.

So far, only land practice has been discussed, but there is also room for vast improvement on board ship. The great drawback in this case is that marine engineers are called upon to burn coals of constantly varying quality. This is, of course, one of the chief reasons why mechanical stokers have not been introduced long since.

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[1] *Power Production in the United Kingdom*, Manchester Association of Engineers, 1914.

Complete combustion, where mechanical stokers are fitted to water-tube boilers, depends, to a large extent, on the suitability of the fuel for the type of stoker used and the setting of the brick arches. A ship sailing from this country to the East will perhaps bunker in the Bristol Channel with Welsh coal, rebunker at Aden with Newcastle coal, and bunker again for the return journey with Indian coal. Under such conditions it is very hard to work boilers at a uniform standard of efficiency. Also, the conditions prevailing at sea are not conducive to high efficiency in this respect, especially when cargo boats, having arrived at a foreign country, commence a series of short trips from port to port. This means that the main boilers are worked very irregularly, and losses occur when banking fires.

A strict system of fuel economy is, however, enforced on board most of the ships belonging to the larger companies, with some very remarkable and praiseworthy results. A keen competition very often exists between chief engineers of sister ships, which is directly responsible for various minor improvements which all help towards raising the standard of efficiency.

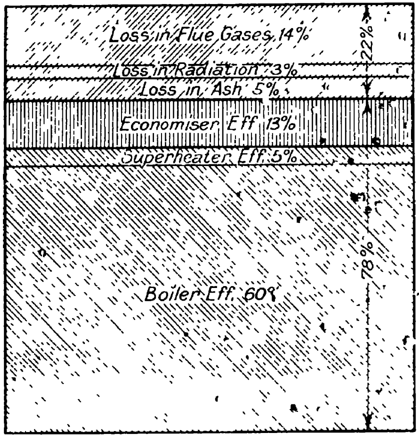

Fig. 1.—Efficiency of a Lancashire Boiler Plant in Good Working Order

A fact that is fully recognized by marine engineers, but often overlooked on shore, is the importance of regulating the steam consumption of auxiliary machinery such as pumps, fans, etc. The connection between this topic and boiler efficiency is to be found in the obligation laid upon the engineer in charge of a boiler plant to use as little steam as possible for his own purposes. The less steam he wastes on auxiliary machinery in his department the more he will be able to send through the main stop-valve on the steam range; and therefore the higher will be the net efficiency of his plant. If he wastes large quantities of steam by neglecting leaky piston rings, faulty valves, etc., he will have less to supply to the factory. There is no detail, however small, that must escape his attention, and his aim must always be to keep everything under his charge in the best condition possible.

(*b*) *Types of Power Unit.*—The types of power unit to which an engineer may be appointed vary very considerably. First of all there is the question of size. The size of a power unit—that is, the size and number of boilers—may vary from one small vertical boiler working at a low pressure to a battery of eighty large-sized water-tube boilers working at high pressure. Then there are the auxiliary appliances, which may be represented by a modest injector or include complete batteries of economizers, separate superheaters in every boiler, a large installation of feed pumps connected by an intricate feed pipe system, and both forced and induced draught fans.

Strictly speaking, the power unit is that part of a boiler house which is actively concerned with the generation of steam. The subsidiary plant is, however, of almost equal importance, and the handling of fuel and ashes, the feed-water plant and pipe system require the engineer-chemist's individual attention. It will therefore be apparent that there is real need for a specialist in the boiler house, who, besides ensuring the correct functioning of each piece of mechanism, will work the whole plant as one homogeneous unit. In addition, such tasks as the supervising of records, which are included in his duties, will fully occupy him when not attending to the details of management previously mentioned.

Very large boiler houses, such as those attached to the electricity generating stations, are generally managed by a large staff of experts.[1] First, of course, comes the boiler-house manager, who is responsible for the correct working of the whole plant, and is in charge of the boiler-house staff. The senior assistant on this staff will be the combustion engineer, whilst the other assistants will be in charge of repair work, disposal of ashes and handling of fuel, supervision of pump house, and so forth. It is not proposed to deal with the individual duties of such assistants, but only with those of the manager. In an ordinary boiler house supplying the necessary power to a factory, the engineer-chemist may have to perform, in addition to the manager's duties, nearly all the duties which, in the case of a large power station, are allotted to assistants.

The next point to consider is the type of boiler. This varies almost as much as the size of the power plant to which it is attached, and is the direct outcome of special requirements which must be fulfilled. There are an enormous number of boiler types in existence, and a description of these alone would fill a very large book. In any case, such a description would serve no useful purpose, and any information the engineer-chemist requires he can find in one or other of the many excellent books which have been written on the design and construction of boilers.[2][3][4]

For practical purposes of supervision and maintenance it is only necessary to consider the six principal types—namely:

Lancashire and Cornish boilers.
Water tube boilers, multiple drum type.
Water tube boilers, header type.
Cylindrical multitubular boilers (generally known as Scotch marine boilers).
Vertical boilers.
Locomotive boilers.

Each of these boilers has been designed to meet special requirements, and will, therefore, generally be found working under the conditions for which it has been designed.

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[1] Nechells Power Station, Birmingham, *Engineering*, No. 2984, p. 291.

[2] *Steam Boilers and Supplementary Appliances*, W. H. Fowler.

[3] *Steam Boilers: Their Theory and Design*, H. de B. Parsons.

[4] *Steam Boilers*, C. H. Peabody and E. F. Miller, Mass. Inst. of Technology.

LANCASHIRE BOILERS

This boiler, by virtue of its simple construction and the very rough treatment it is capable of withstanding, has found universal favour as a steam generator, and is the type generally found in the boiler house attached to an ordinary factory. When properly worked it is economical, and even at high pressures gives excellent results. It does not suffer to the same extent as the other types from the ill effects of impure feed water

Cornish boilers are very similar to Lancashire boilers, excepting that a Cornish boiler is only fitted with one flue, whilst a Lancashire boiler has two.

There are a host of modified Lancashire boilers, known under a variety of names, but no difficulty should be experienced in applying the remarks made in these pages upon the general Lancashire type to any of its modifications.

The reader's attention may here be drawn to a mistake that is often made through confusing Lancashire boilers with the Galloway class of boilers. The furnaces in many Lancashire boilers are fitted with cross-water tubes in the flue, and these are spoken of as "Galloway tubes" There is a vast difference between this construction and the real Galloway boiler The real Galloway boiler is a boiler in many respects similar to the Lancashire type, but the two furnace tubes develop into one large oval flue in which are situated a number of cross-water tubes, and the length of which is about three times that of the grates in the furnace tubes It is the presence of these cross-water tubes that causes the loose expression, "Galloway boiler," to be used when in reality only a Lancashire boiler fitted with cross tubes in the flues is meant.

WATER TUBE BOILERS

The water tube boiler is essentially a power station boiler, being specially suited to conditions in which it is necessary to generate a large amount of energy on a limited floor space In certain forms of construction these boilers can be carried to a great height, thus largely increasing the power generated per square foot of ground occupied.

Although the water supplied to this type of boiler must be absolutely pure, feed-water trouble is practically non-existent in modern power stations where the boilers are fed with properly de-oiled condensate, and there only arises the question of suitably treating the small percentage of "make up" feed water which is required to make up for the loss by leakage at glands, etc.

On account of the high efficiency at which they may be worked, the small space they occupy relatively to their power-producing capacity, their eminent suitability for high pressures, and the speed with which they raise steam, water tube boilers are becoming more and more popular. They are used exclusively and with great success in the Royal Navy, and are also being introduced into the mercantile marine for ships having a comparatively high speed, such as large transatlantic liners.

Many large works have a complete electric power station of their own and, in such cases, where the boiler plant not only has to supply high pressure superheated steam to the turbo-generators, but also to meet the demands of the factory, water tube boilers have completely displaced the Lancashire boiler.

The water tube boilers commonly in use are of two distinct types: the multi-drum and the header type. The multi-drum boiler consists of a large number of tubes, either straight or curved, which connect a number of steam and water drums. The disposition of the drums and shape of the tubes vary according to the design of the maker. The number of makes is large, but the differences are only in structural details. In all these designs the boiler tubes are expanded direct into the shell plates of the steam and water drums. Stirling boilers belong to this type.

WATER TUBE BOILERS, HEADER TYPE

In the header type of water tube boiler a series of tubes is connected by front and back headers. These headers are in turn connected to a steam drum, and in some cases to a water or mud drum. The great advantage of this class of boiler is that by removing the small doors, or handhole covers, which are fitted opposite each tube, all the tubes are made accessible for thorough inspection or cleaning. This class of boiler has been introduced on board ship with great success; and it is also very suitable for power station work, because it may be built to a great height with super-imposed economizer and air heater.

In this connection it is worthy of note that in several instances a very useful compromise between Lancashire and water tube boiler has been made. To meet the requirements of a fairly large, but fluctuating, demand for steam, two water tube boilers working in conjunction with three Lancashire boilers make a good arrangement. If one Lancashire boiler is a reserve boiler, allowing a certain margin of power to fall back upon when cleaning is necessary, the plant will nominally consist of two water tube boilers and two Lancashire boilers. The water tube boilers will take the brunt of the load; their combined evaporation will be about equal to the average steam demand, and the two Lancashire boilers, which may be worked with a comparatively good efficiency at small loads, will act as a regulating set to keep the pressure constant.

CYLINDRICAL MULTITUBULAR BOILERS

(SCOTCH MARINE BOILERS)

This type of boiler is almost exclusively used on board ships. It is made single and double-ended. The latter may be roughly described as two single-ended boilers placed back to back with one common shell. The boiler consists of a cylindrical shell, in the lower half of which are two, three, or four furnaces, according to the size of the boiler. Each of these furnaces, at the back end, opens into a combustion chamber supported from the back of the boiler, and also at the sides. The upper part of the combustion chamber is connected with the front of the boiler by means of a nest of tubes.

The main difference between boilers of this type and water tube boilers as regards the passage of the gases is that in the marine boiler the products of combustion pass *through* the tubes, while in the water tube boiler they pass *round* the tubes.

Scotch marine boilers can stand remarkably rough treatment, but they have one great drawback. The shell plates are necessarily very thick (an average figure being 1¼ inches) on account of the large diameter of the boiler, which is sometimes 18 feet, and the joints in the shell itself, and where the shell and end plates meet, are inevitably very rigid. It is therefore necessary to allow these boilers plenty of time when raising steam, so that a gradual and very uniform increase in temperature may take place.

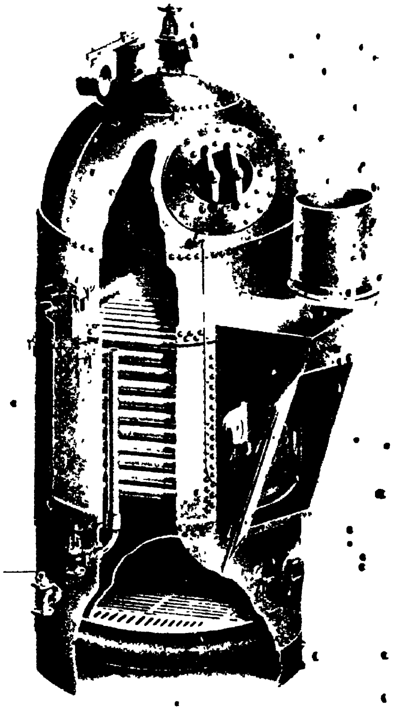

Fig. 2 — Coal-Fired Cochran Boiler with Shell partly Cut Away to show Interior

VERTICAL BOILERS

The vertical type of boiler is not so common as those already mentioned. It is largely used on board ship as a donkey boiler—that is, for generating steam when in port, so that main boilers may be shut down for cleaning. It is also found supplying steam to small factories where space does not permit of a Lancashire boiler being installed.

Illustration No. 2 shows a Cochran boiler, which is the best known boiler of this type, and has also been adapted for use where large quantities of waste gas are available. Other makes of vertical boiler are most commonly met with, in a smaller form, on cranes, steam road wagons, etc.

LOCOMOTIVE BOILERS

This boiler practically consists of a closed shell, in which are situated a large number of small tubes, the products of combustion passing straight through the tubes and then away.

Locomotive boilers are, as the name implies, fitted to all locomotives and other similarly propelled machines such as traction engines and steam rollers. They are also occasionally found as stationary boilers, chiefly in agricultural districts. Outside their employment on the railways they are not very important.

It is not proposed to deal at length with this type of boiler because every railway company has evolved a special design of boiler to suit the specific requirements of its services, and the whole organization is regulated accordingly.[1] The engine sheds each have a highly-trained staff who know the exact requirements of the particular design of boiler fitted to their company's engines, and the whole system of feed-water supply is regulated to suit the prevailing service conditions. The supervision and maintenance of locomotive boilers is a study by itself, and those desiring further information should consult the special literature of that subject.[2] [3] [4]

Each of the six types of boiler is, of course, represented by a very large number of makes, which fact alone will give a slight indication of the great diversity of steam-raising apparatus which the engineer-chemist may be called upon to manage efficiently.

So far, only the boilers themselves have been described, but all modern power plants, and a large number of the older installations, are fitted with auxiliary appliances, such as economizers, superheaters, machinery for producing artificial draught. All, without exception, are provided with the necessary arrangements for feeding the boilers. An almost incredible variety of machinery comes under the heading of auxiliary appliances, and as, with very few exceptions, each sort of auxiliary apparatus can be combined with several types of boiler, innumerable variations may be noticed in the details of installations at two plants in the same town and attached to works in the same industry. Such great difference between classes of apparatus designed for the same purpose exists nowhere else in industry.

The engineer-chemist has a large field to study before he may consider himself proficient, and even then it is the adaptation of personal knowledge to the particular requirements of each individual plant, and not the wholesale application of standard facts, that will produce high efficiency, and so prove his ability as a specialist.[5] The subsidiary plant, comprising feed water plant, automatic machinery for the handling of fuel and refuse, and such other plant as is attached to a boiler house, with only an indirect effect on the efficient working of the plant as a whole, does not call for great scientific knowledge, but rather for practical controlling ability.[6]

(c) *Layout and Efficiency.*—The efficiency at which a boiler plant may be worked depends to a large extent upon the layout. Great care should therefore be taken when choosing a site for a new plant. This is especially important for electric power stations and large factories, and the claims of the boiler house merit the most painstaking thought before the site is definitely selected. The two main considerations are proper facilities for transporting fuel and an abundant supply of good clear water.

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[1] *Engine House Practice*, F. H. Clark, Inst. Mech. Eng., 1910.

[2] *Modern Locomotive Practice*, C. E. Wolff, B.Sc.

[3] *Locomotive Fuel Economy*, G. H. Baker, Railway Education Association.

[4] *Superheated Steam in Locomotive Service*, W. F. M. Goss, University of Illinois

[5] *Working of Steam Boilers*, E. G. Hiller.

[6] *Steam Power Plant Engineering*, G. F. Gebhardt.

If it is possible to place the new works near a suitable waterway, both problems are solved. A suitable waterway would be a river or canal, the water of which is free from an excess of scale forming salts in solution, is at all times reasonably clear, and is at no time subject to pollution by the influx of sewage or objectionable chemicals from other factories situated in the vicinity. Also, such a waterway must be of sufficient breadth and depth to permit barges of fuel to pass at all times without reference to tide or season. Further, it should lead to a reliable source of coal or other fuel, preferably to a colliery direct, without undue liability to stoppages in transit.

The cheapest method of transporting fuel is by water, and as coal is the fuel most generally used to-day, reference is made to a colliery in the preceding sentence. In the future, coke will probably take the place of coal, and the word "colliery" will then have to be deleted and "gas works" inserted. As matters stand to-day, a cheap steady supply of fuel and plenty of good clean water are the chief considerations

So much for new plants. More important, however, is the economical working of the hundreds of boilers on existing plants. This is very often a difficult problem.[1] The actual trouble in most cases is the very complicated nature of the power installation, especially in the boiler plants of firms that have been established a long time. The firm originally started in a small way with perhaps two Lancashire boilers, as time went on, additional machinery was installed in the factory, and the load on the boiler house was increased, the original two boilers, probably low-pressure boilers, were no longer able to supply the necessary steam, and an additional boiler was installed. This new boiler was probably slightly larger, if space permitted, and possibly fitted with a superheater Then one of the original boilers was condemned and a new boiler No. 1 was installed in its place. This boiler had necessarily to be of the same diameter as the old boiler—certainly not larger but in order to improve the output of the plant it was possibly a little longer, say a 30-foot boiler in place of the original 28-foot boiler. At a later date, new high-pressure machinery was installed in the factory, the old plant having become obsolete, and an additional boiler, No. 5, was bought, although at present four boilers only are working, one old boiler having been replaced by a new one. There was no room for boiler No. 5 (and an economizer) next to the existing plant, and it was placed in some other suitable position with special reference to the chimney. A new flue became necessary as the old one was too small to deal with all the products of combustion, and this necessitated cutting a new opening in the chimney. Boiler No 5 was probably installed to supply steam at a higher pressure direct to some of the new machinery and therefore had a pipe system of its own. To meet emergency requirements, it was fitted with a special branch connection to the previously existing steam range with reducing valve interposed. At a later date, further improvements were undertaken by installing an induced draught fan and more economizers.

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[1] *Economical Working of Boilers*, E. Wilson

Illustration No. 3 shows an induced draught fan, which should always be arranged to have a straight "pull." The discharge can be arranged in any manner desired.

It will thus be seen that the boiler plant of an old factory may be a complicated arrangement of power units, calling for considerable skill on the part of the engineer-chemist to work them efficiently and as far as possible as a homogeneous unit. Additions made to the power plant at successive stages present no great difficulty, and with expert advice can well be carried out in such a manner that the plant at all times may be worked at a high efficiency.

Unfortunately, however, firms buy boilers according to catalogue performance, and expect a boiler to produce the same results when added to an old plant, as if working under the conditions prevailing on a new plant, where the draught is sufficient to burn economically the fuel required to give the stated evaporation.

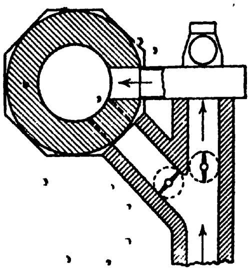

FIG. 3.—POSITION OF INDUCED DRAUGHT FAN.

This is not the only trouble. The new boiler is very often set by local bricklayers under the supervision of the firm's own mechanic. All may be skilled men in their trade, and capable of excellent work when called upon to construct an edifice out of bricks. But to set a boiler in a limited space in an existing plant and under difficult conditions is a job for specialists, requiring, in addition to expert knowledge of materials, special methods of construction, etc., a thorough acquaintance with stream line motion.

One of the immediate results of using ordinary labour to set a Lancashire boiler is likely to be that the draught in the side flues, instead of being ample under the heaviest load, falls far short of the mark even at light loads. Under these conditions fuel cannot be economically utilised, and the evaporation of the boiler is limited by the maximum intensity of draught obtainable. Most boiler plants cannot maintain the steam-pressure required of them, and in trying to remedy the deficiency the firemen offer the boilers more fuel than can be consumed economically with the available supply of air, and the volatile products escape unburnt, causing black smoke.

CHAPTER II

COMBUSTION OF FUEL

(*a*) *Solid Fuel.* By far the majority of power plants use coal as fuel for steam-raising purposes. The remainder use such fuel as best suit their respective needs. These other fuels may be classified as follows:

Fuels of low calorific value, such as town refuse, waste from saw mills, dry and wet sugar-cane (called megasse and bagasse), wood logs, rice husks, spent tan, peat, etc.

Liquid fuels, such as Mexican, Persian, Texas, Borneo, Californian, and Roumanian crude or partially refined oils.

Waste gas from blast furnaces, producer and town gas, pulverized fuel.

To the solid fuel class belong all the known varieties of coal from good anthracite down to inferior browncoal. The following table gives a selection of such fuels with their approximate analysis and calorific value.

TABLE I

Approximate Analysis and Calorific Value of Various Fuels

Name	C	H	O	S	Moisture	Ash	B.T.U.
Charcoal	94·0	2·4	1·3		1·0	1·3	15,100
Anthracite	83·5	5·0	3·6	1·1	1·6	4·9	15,000
Welsh	86·0	3·0	3·0	1·0	3·0	4·0	14,200
Coke (dry)	88·0	1·0	3·0	1·0	3·0	4·0	13,200
,, (wet)	68·0	0·4	2·6	1·0	21·0	7·0	9,900
Northumberland	80·3	4·8	6·7	1·2	3·2	3·8	14,000
Derbyshire	78·8	4·6	7·1	1·0	4·6	3·6	13,800
Lancashire	77·9	5·4	9·6	1·5	0·7	4·9	14,000
Scotch	78·1	5·5	9·1	1·1	1·6	4·0	14,070
Lignite (dry)	70·0	4·0	9·0	1·0	9·0	7·0	12,100
Peat (dry)	50·0	4·0	12·0	5·0	12·0	17·0	9,000
Wood	41·0	4·5	37·0		16·0	1·5	5,900
Browncoal (briquettes)	55·1	4·4	23·1	0·4	11·6	5·4	8,920
Browncoal	29·0	2·7	7·5	1·3	53·0	6·5	5,325

All solid fuels contain carbon, hydrogen, and oxygen, in addition to a variety of other substances. The extent to which carbon, hydrogen, and oxygen are present in coal influences its character, and therefore the treatment it should receive when being burnt under boilers. Failure to grasp the significance of this fact is one of the chief reasons why boiler plants are worked so inefficiently, and so often pollute the atmosphere with black smoke. To utilize coal to its fullest extent we must understand the nature of the coal and treat it accordingly; but few firemen appreciate the fact that *all* coals are *not* alike.

In order to distinguish the various kinds of coal they have been given such names as anthracite, bituminous, semi-bituminous, with additional descriptive adjectives as "caking," "coking," and others which describe their special behaviour when being burnt. This terminology is very vague, and although a fireman may know the difference between anthracite and a soft bituminous coal, this knowledge is of ittle use, because the difference is so great that he will never be called upon to burn these two fuels under the same boiler. Give him two different semi-bituminous coals, each of which requires special treatment, and he is at a loss what to do. The determination of the method of firing different coals, which may come from the same coalfield, requires great skill, and should be entrusted to a competent specialist. The present system of burning different fuels, which are regarded as identical because they happen to come under the same general description, might well be compared to that of a hospital in which all patients suffering from throat trouble should receive the same treatment irrespective of the cause or nature of the complaint.

Carbon is an element represented in chemistry by the symbol C, and is a solid at atmospheric temperature and pressure. Oxygen and hydrogen are both gases at normal temperature and pressure. Each of these three elements is able to combine with one or both of the remaining elements to form a very large number of compounds, some of which are solid, others liquid, and the remainder gaseous under ordinary conditions. Some of the carbon in the coal is combined with the hydrogen also present in the form of compounds known as hydrocarbons, but the greater part, which is uncombined, is referred to as fixed carbon.

The atmosphere, as far as the combustion of fuels is concerned, consists of oxygen and nitrogen. The proportion in which these two gases are present is as follows:

By volume ..	Oxygen	20·96 per cent.	Nitrogen	79·04 per cent.
By weight ..	„	23·2 „	„	76·8 „

Nitrogen is, of course, an inert gas, and takes no positive part in any combustion problem. It may therefore be ignored until calculations are made in which the actual volume of *air* is required, the volume of *oxygen* required having been ascertained. The oxygen is the all-important factor because it supports combustion, and the whole question of the economical utilization of any fuel simply resolves itself into supplying a quantity of air which will contain the necessary amount of oxygen to ensure the complete combustion of the fuel under consideration.

All fuels are considered in the same manner, but as coal is that most commonly used and the most complicated, an average bituminous coal will be taken as representative example. The chief constituents of such a coal are carbon, hydrogen, oxygen, sulphur, nitrogen, ash, and water, the carbon and hydrogen being present both in a free state and combined as hydrocarbons. During the process of burning coal the raw material undergoes two completely independent changes, which may, and generally do, take place at the same time - namely, the separation of the volatile matter and the decomposition of the fixed carbon. The chemical reaction of the fixed carbon and oxygen to form carbon dioxide produces heat which causes the ignition of the volatile gases which leave the coal during the coking stage. Whenever the heat caused by chemical union is sufficiently intense to raise the resulting substances to a temperature at which they emit light, the act of union is termed "combustion." In order to find the theoretical heating value of any coal, it is necessary to treat each of the constituents, carbon, hydrogen, oxygen, and sulphur, as if they existed separately, and to work out their individual contributions to the heating value of the fuel. The carbon constituent is by far the most important because it is present to the largest extent, and when 1 pound of carbon is completely burnt to form carbon dioxide, 14,500 British thermal units are generated. It should be remembered, however, that this is only the case when the carbon is completely burnt, which is rarely the case in actual practice. When a pound of carbon is partially burnt to form carbon monoxide, which happens when the air supply is insufficient to produce complete combustion, only 4,350 heat units are liberated.

The difference between these two values, amounting to 10,150 heat units, need not be entirely lost, for the carbon monoxide can combine with the necessary oxygen, when this becomes available, and, being itself an inflammable gas, can burn to form carbon dioxide, and by doing so generate 10,150 heat units which, added to the 4,350 already evolved, equal 14,500 heat units or exactly the same amount as if the carbon had all been converted into carbon dioxide in the first instance. The figures clearly illustrate the extreme importance of ensuring a complete reduction of the carbon to carbon dioxide whilst the heat units liberated can be absorbed by the heating surface of the boiler. The carbon monoxide often escapes, and does not ignite until it leaves the chimney, when sufficient oxygen becomes available, and all the heat is then lost.

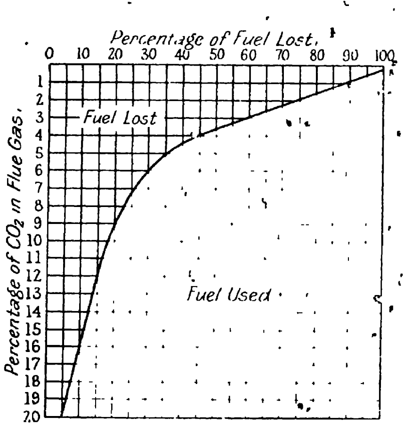

FIG. 4. - RELATIONSHIP BETWEEN CO_2 AND FUEL LOSS

Temperature of exit gases 500° F.

Fig. 4 shows the relationship between the percentage of carbon dioxide in the flue gases and the percentage of fuel lost. The average boiler plant is worked with about 8 per cent. carbon dioxide, and 12 to 14 per cent. may be taken as very good if continually recorded.

Unfortunately, to solve the problem of supplying sufficient air to provide the oxygen required for combustion, the air must be able to mix intimately with the burning coal, and this depends upon skilful stoking and correct design of grate for the kind of fuel being burnt. The air should be supplied by a large number of small openings in the grate instead of through a few large slots. This condition is difficult to obtain in practice unless the air is forced through the grate by using some arrangement of steam jets, because the small openings rapidly become choked with clinker and ashes, and the result is one solid air-tight surface.

When 1 pound of pure hydrogen is burnt under calorimetric conditions, 62,060 British thermal units are generated. The hydrogen in British coal varies from 4½ to 5¾ per cent. Some of the hydrogen in burning combines with the oxygen present in the fuel, whilst the remainder unites with the oxygen supplied with the air, all the hydrogen being converted into water, that is steam.

In actual practice, to estimate correctly the heating value of a fuel, it is necessary to deduct the oxygen converted into water due to the hydrogen present in the fuel. The hydrogen in the coal is all in chemical composition with the carbon, and in very many various forms of hydrocarbons. The proportions between these are too numerous and erratic to enable them to be taken into account in a simple formula for heating value. Moreover, some of the hydrocarbons are unstable, and it is now fairly well established that during the process of distillation out of the coal by heat —which process drives them off above the grate as unburnt gases—and the subsequent process of combustion in the furnace above the grate, they change their forms once, twice, or even sometimes thrice. Finally, when a certain temperature is reached, the hydrogen separates definitely from the carbon and unites with the oxygen of the air-supply and with that contained in the coal itself, to form steam.

Oxygen is also present in the fuel, and this, when liberated from the coal, assists the oxygen supplied with the air, and therefore forms part of the oxygen required for combustion. Part of the oxygen combines with the hydrogen in the coal to form steam, and as this is not available for purposes of combustion, allowance must be made accordingly when calculating the heating value of the fuel. The percentage of oxygen varies widely from 4 to 10 per cent.

The sulphur content also varies very considerably, but as the heat generated when 1 pound of sulphur is burnt to form sulphur dioxide is very low (only 4,060 heat units), the percentage of sulphur contributes little to the calorific value, but is of more importance when considering the corrosive action of the flue gases. The nitrogen present is very small, and as the gas is inert need not be considered.

The most important contribution of heat units when 1 pound of coal is burnt is that due to the combustion of the carbon, and therefore the percentage carbon content of a fuel is a good indication of the heating value of that fuel.

Fig. 5 shows the relation between the carbon content of a fuel and its approximate heating value. It has been stated that when 1 pound of carbon is reduced to carbon dioxide 14,500 heat units are liberated, and that 1 pound of hydrogen, when burnt, produces 62,060 heat units. One pound of hydrogen therefore gives 62,060÷14,500 times as much heat as 1 pound of carbon. A fuel containing only carbon and hydrogen to the extent of C and H per cent. by weight would therefore give 14,500 C+62,060 H British thermal units, or, according to the above relationship, C+ 4·28 H.

All coal contains oxygen, and this combines with the necessary hydrogen to form steam according to the formula H_2O. The atomic weight of hydrogen is 1, and that of oxygen 16; therefore, 2 atoms of hydrogen combine with 16 of oxygen by weight, or, in other words, 8 parts of oxygen by weight combine with 1 part of hydrogen. In order to ascertain the quantity of hydrogen which will combine with oxygen to form steam, it is only necessary to divide the number of oxygen units by 8. Thus,

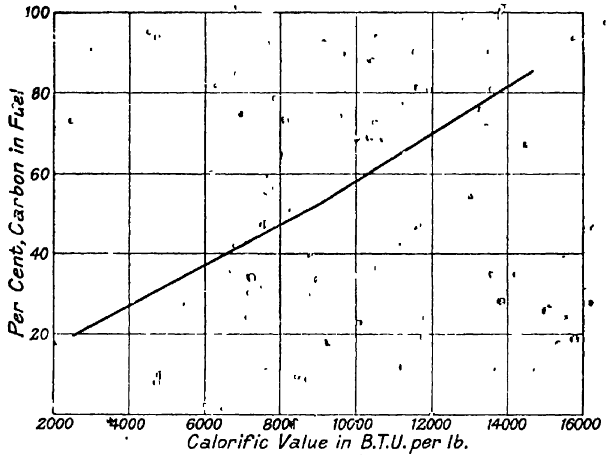

FIG. 5.—RELATIONSHIP BETWEEN CARBON CONTENT OF A FUEL AND ITS HEATING VALUE

if H is the total hydrogen present, the net hydrogen which can be burnt, when finally liberated from the compounds in which it is present, to contribute heat units at the rate of 62,060 for every pound will be $H - \frac{O}{8}$. The formula for calculating the calorific value of a fuel then becomes $14{,}500\,C + 62{,}060\left(H - \frac{O}{8}\right)$.

The last item to be considered is the sulphur in the coal. When 1 pound of sulphur is burnt under calorimetric conditions 4,060 heat units are generated, or, compared with carbon, 14,500 ÷ 4,060, which is equal to 3·56—that is, 3·56 pounds of sulphur must be burnt to produce the same heat as that generated by 1 pound of carbon. If the sulphur content of a coal be divided by 3·56, we shall obtain the weight of carbon which would generate the same heat. It is therefore necessary to add $\frac{S}{3{\cdot}56}$ or 0·28 S to the equation already obtained, to include the heat contributed by the sulphur, expressed in terms of carbon—that is, 14,500 B.T.U. per poun The heating value of 1 pound of coal then becomes:

$$14{,}500\,C+62{,}060\left(H-\frac{O}{8}\right)+0{\cdot}28\,S\times 14{,}500;$$

dividing throughout by 14,500:

$$14{,}500\left\{C+4{\cdot}28\left(H-\frac{O}{8}\right)+0{\cdot}28\,S\right\}$$

Since the analysis of a fuel is always given in percentages, the carbon, hydrogen oxygen, and sulphur being expressed in so many parts in a hundred, the equation must be divided by 100, which gives:

$$145\left\{C+4{\cdot}28\left(H-\frac{O}{8}\right)+0{\cdot}28\,S\right\},$$

and in this form it will be recognized as Dulong's formula for finding the theoretical heating value of a coal from its chemical analysis. The actual value of the heat units generated when 1 pound of each of the four constituents is burnt varies slightly according to different authorities, but the figures given have been chosen on purpose to show how this important formula is obtained. When coal is burnt the carbon is converted into carbon dioxide and certain other gases are formed by the disintegration of the hydrocarbons, the most common being ethylene (C_2H_4), methane (CH_4), free hydrogen, and to a lesser degree several other products, of which the most important is sulphur dioxide. These, with the exception of the sulphur dioxide, which will combine with steam to condense and form sulphuric acid, may all be burnt to form carbon dioxide and steam, either directly or indirectly. Ethylene and the higher hydrocarbons undergo an indirect decomposition in the process. Ethylene easily decomposes at high temperatures, and, due to its own heat of combustion, is reduced to methane (CH_4) and carbon (C), according to the equation $C_2H_4=CH_4+C$.

The newly-formed carbon remains in suspension in the furnace gases and contributes to the luminosity of the flame, provided a sufficient supply of air is present to assist in the combustion. The methane formed is further decomposed into carbon dioxide and water.

Should the supply of air be insufficient, or should the flame be subjected to a cooling effect, such as might be produced by coming into contact with comparatively cool surfaces so that the temperature drops below 1240° F., which is the ignition point of carbon, the carbon will deposit as soot. This phenomenon may be distinctly seen even with a fairly bright fire, and the formation of these sooty flames must be avoided. Such flames are formed, to a considerable extent, when highly-bituminous coals are burnt under water-tube boilers, because the large amount of volatile matter released has not sufficient time to be entirely consumed—completely burnt to carbon dioxide—before coming in contact with the large and comparatively cool heating surface of the boiler. Large combustion chambers are therefore of great importance in the case of water-tube boilers.

Fig. 6 shows the combustion chamber of a water-tube boiler arranged to ensure complete combustion.

When the layer of coal is very thick—that is, when the air, in trying to pass through the fuel bed, meets with great resistance—a considerable amount of carbon monoxide is formed, which, as already explained, will, if the temperature has not fallen too low, burn to form carbon dioxide on mixing with an adequate supply of air. If, however, there is present a greater quantity of air than is theoretically necessary completely to consume the fuel, a rapid drop in temperature takes place.

Fig. 7 shows the relationship between the carbon dioxide actually obtained and the ratio of air actually supplied to that theoretically required for combustion. This ratio increases very rapidly when the amount of carbon dioxide is low.

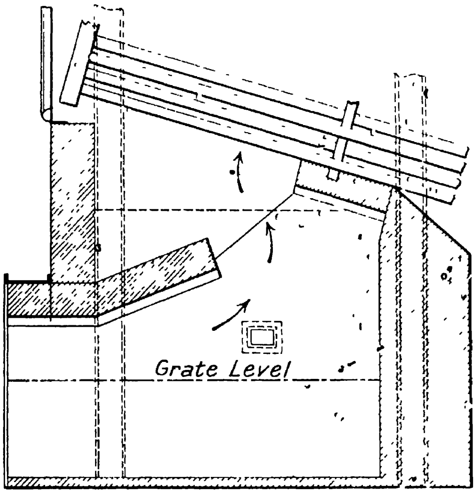

Fig. 6. Combustion Chamber of a Water-Tube Boiler

If the excess of air is great, the nitrogen introduced into the furnace together with the oxygen will dilute the flue gases to such an extent that the resulting temperature will be very low. All flame temperatures vary between the extreme case when all the carbon is converted into carbon monoxide, at a temperature of 2700° F., to the other extreme when all the carbon is reduced to carbon dioxide with a resultant temperature of 1900° F.

In actual practice the temperatures are nowhere near these figures because it is impossible to burn fuel under ideal conditions and because the component parts of the fuel are not all free, but in varying combinations. Experience shows that the maximum temperature varies to a great extent on account of the different reactions taking place simultaneously, and also because some of the heat is absorbed by the boiler as quickly as it is generated.

Although the engineer-chemist is little concerned with research in the abstract, he must possess a sufficiency of theoretical knowledge to enable him so to regulate the air-supply that all the carbon shall be burnt to carbon dioxide, and at the same time to avoid any excess which will cool the volatile gases to such an extent as to cause them to pass away as smoke instead of being burnt.

The construction of the furnace, including the design of the grate and the weight of firebrick and its disposition around the grate, is naturally a very important matter.

The design of the grate governs the method of supplying the air; the firebrick, when in a state of incandescence, acts as a valuable heat receiver, and materially assists to ignite the volatile products. Some very ingenious designs have been thought out for the purpose of getting the best results in these respects, examples of which are furnished by the various types of coking arch applied to the mechanical stokers of water tube boilers and by the patent fire-bridges fitted to Lancashire boilers.

The heating value of a fuel is rarely ascertained by examination of its chemical composition, but by burning a known weight in the laboratory in a special calorimeter. The formula for calculating the theoretical heating value of coal has been given, because it clearly shows the influence which the carbon content has on the heating value, and indicates the complex reactions which take place in a furnace.

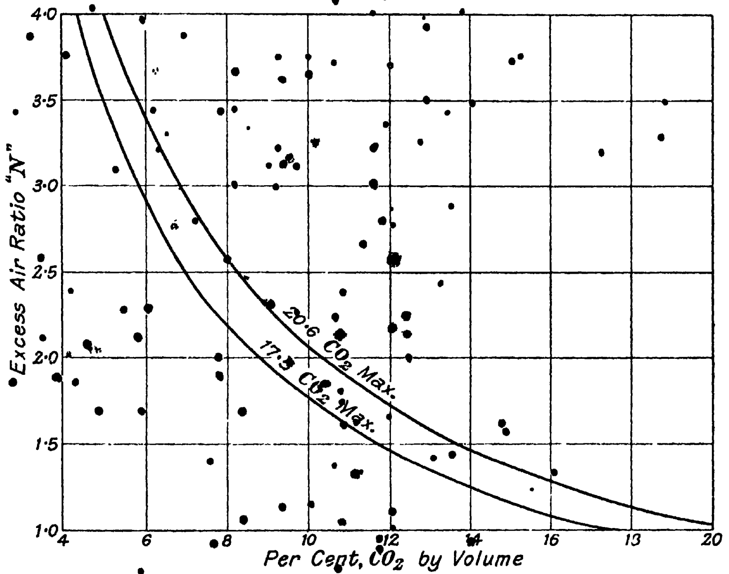

FIG. 7.—RELATIONSHIP BETWEEN CO_2 OBTAINED AND THE RATIO BETWEEN AIR SUPPLIED AND AIR NECESSARY FOR COMBUSTION.

It is now necessary to consider the amount of air theoretically required to effect complete combustion of the various ingredients of a fuel, and here, again, the air required by each constituent part is calculated as if that part existed by itself, and not partly in combination with the other elements present.

The atomic weights of carbon and oxygen are 12 and 16 respectively. Therefore, when carbon burns to form carbon dioxide, 12 parts of carbon combine with 32 of oxygen by weight, according to the formula CO_2, or, taking the pound as the unit, 1 pound of carbon requires $32 \div 12$, or $2\frac{2}{3}$ pounds of oxygen for combustion. The atmosphere contains 23 per cent. oxygen and 77 per cent. nitrogen by weight;

therefore, in order to obtain $2\frac{2}{3}$ pounds of oxygen it is necessary to use 11·5 pounds of air $\left(\frac{100\times2\frac{2}{3}}{23}\right)$. Similarly, when the hydrogen burns to form steam, every 2 atoms of hydrogen combine with 1 atom of oxygen as the well-known formula H_2O indicates. The atomic weight of hydrogen is 1, and that of oxygen is 16. Therefore, 2 atoms of hydrogen combine with 16 of oxygen, or, converting this ratio into pounds, 1 pound of hydrogen requires 8 pounds of oxygen $\left(\frac{16}{2}\right)$. 34·8 pounds of air are required to supply 8 pounds of oxygen $\left(\frac{8\times100}{23}\right)$. Therefore, if coal contained no oxygen, the air required would be $11{\cdot}5\,C + 34{\cdot}8\,H$ pounds, but, as already explained, when finding the formula for the theoretical heating value of a coal, the oxygen in the coal combines with some of the hydrogen, and this amount of oxygen must therefore be subtracted from the total required. The formula then becomes:

$$11{\cdot}5\,C + 34{\cdot}8\left(H - \frac{O}{8}\right)$$

The average amount of air theoretically required after taking into consideration ash and moisture is about 11 pounds, or, roughly, 135 cubic feet, per pound of coal. If every piece of coal were in suspension so that the air could pass freely around it, and there were no resistance at all, this low figure might be obtained. In practice much more is required. Even with very thin fires, and these are undesirable, because it is difficult to avoid air-leaks, the air has to overcome a certain resistance in passing through the bed of fuel. The thicker the layer of fuel on the grate, the longer the carbon dioxide, which as a heavy gas needing to be cleared away by draught, will form a blanket round the fuel, and so prevent the free access of more air. Another interesting point made clear by the formula is that, compared with carbon, hydrogen requires, roughly, three times as much air for complete combustion.

It follows that with fuel such as good coke, which is practically pure carbon, the air-supply can be regulated with comparative ease and certainty of a satisfactory result. Black smoke, which is mainly due to the absence of the relatively large volume of air required to burn the hydrocarbons, becomes impossible when burning coke, for the latter contains no hydrogen. Expert supervision is as necessary with coke as with other fuels, if maximum heating value is to be obtained at minimum cost, but so far as air regulation is concerned coke does not require the constant changes that are necessary in order to burn the volatile products freed during the combustion of coal. In supplying the oxygen necessary for this purpose a large amount of nitrogen has to be introduced into the furnace and heated to the same temperature as the products of combustion, thus carrying away a large quantity of heat which can only be partially recovered by auxiliary appliances.

In practice, 16 to 22 pounds of air for every pound of coal burnt may be considered efficient working, but negligence in operation and bad design of apparatus are often responsible for the figure rising as high as 25 to 30 pounds of air for every pound of coal, according to draught available. From this it will be seen that the greatest skill is required for the efficient burning of coal in its raw condition.

Immediately raw coal, or green fuel as it is sometimes called, is thrown on to the grate the volatile products are liberated, and unless the right amount of air is present and the furnace supplies sufficient extra heat—by radiation from brickwork, for example—these valuable gases will not ignite, but pass away as smoke. In other words, fine particles of carbon are held in suspension, and their whole value as heating units is lost. Smoke is unconsumed carbon, and represents valuable fuel thrown away. A slight haze at the top of a chimney is a very good sign, because this is evidence that the gas leaving the chimney is rich in carbon dioxide. If the air-supply is regulated so exactly that only the minimum quantity theoretically required for combustion is supplied, there is a great danger of a considerable quantity of carbon monoxide being formed, which will not burn to form carbon dioxide because air will not be present in sufficient quantity to complete the process of combustion. Carbon monoxide causes no haze when leaving the chimney.

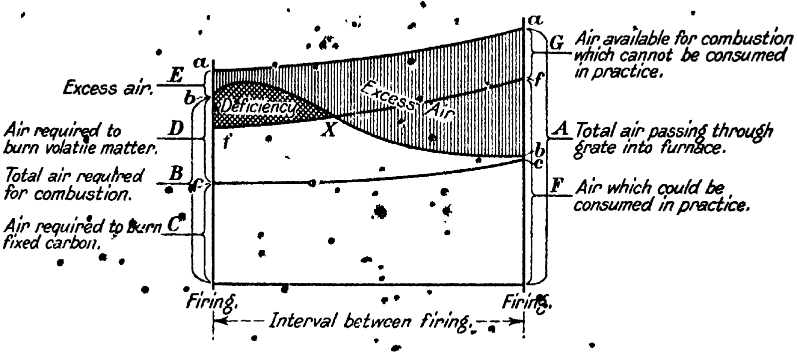
a
E
Excess air.
b
Deficiency
Excess Air
X
f
D
Air required to burn volatile matter.
B
c
Total air required for combustion.
C
Air required to burn fixed carbon.
a
G
Air available for combustion which cannot be consumed in practice.
f
A
Total air passing through grate into furnace.
b
c
F
Air which could be consumed in practice.
Firing.
Firing.
Interval between firing.

FIG. 8.—GRAPHICAL REPRESENTATION OF QUANTITIES OF AIR PASSING THROUGH A GRATE DURING INTERVALS BETWEEN FIRING.

In the ordinary process of firing a boiler by hand, when the carbon has become ignited and the volatile products have been distilled, the large amount of air necessary at the commencement is no longer required, because the carbon that is left needs a relatively smaller amount of air in order to burn to carbon dioxide.

Fig. 8 is a graphical chart showing approximately the quantity of air required to consume a charge of fuel. The width of the diagram represents the time which elapses between any two consecutive firings. On any base line two perpendiculars are erected, the distance between them representing the period of time between firing. Draw a line *cc*, and assume the space underneath it to represent the total amount of air, *C*, which the fixed carbon in the fuel requires for complete combustion. Such line, and all others which represent a quantity of air passing through the grate and [illegible]tering the furnace, will have a slight rise, because when the bed of fuel becomes [illegible]inner through the reduction of the coal in burning, the resistance the inrushing [illegible]r has to overcome will decrease, and air will pass through the bars in increasing quantities. Draw a second line *ff* and assume the space between this and the line *ee* to represent the amount of air theoretically required to consume the volatile matter. Then the whole area under the line *ff*, down to the base line, represents the amount of air that should, theoretically, pass through the grate.

When a charge of green fuel is newly placed in the furnace, the volume of gases distilled is very great, and if only the amount of air theoretically needed for combustion is introduced—that is, such a quantity as might be represented by the line *ff* — this will be insufficient during the first part of the interval between firings, and in excess during the latter part. The distribution of air as required in practice is probably more accurately indicated by the line *bXb*, and the area above the line *fX* represents an insufficient supply of air, which is the cause of black smoke. If this smoke could be kept and returned to the furnace when the first "rush" has taken place, the air represented by the area under the line *Xf* could be fully utilized. As this is impossible, sufficient air must be admitted from the very first, and since it is not safe to supply the minimum theoretically required, a very small excess must be allowed. The air which should be supplied to a furnace can therefore be represented by the line *aa*. The line *bXb* varies in shape for different fuels and, as shown, is approximately correct for a bituminous coal. With coke the line would first rise slightly above the line *ff*, but not nearly as much, and it would sooner follow the line *ff*. The line *ff* would be much nearer to the line *ee*, because the air required to burn the volatile matter is very much less, and the excess air would be very small, so that the total air *A* entering the furnace would approximate *F*, which can all be utilized in practice.

The air supplied to a furnace should be constantly regulated, and several ingenious types of apparatus have been invented which automatically regulate the secondary air-supply. The secondary air supply is that which is admitted over the fire at the front or at the back in order to furnish the oxygen necessary for the combustion of the volatile gases. On account of its somewhat intricate construction and the distaste of British firemen for anything "finicky," such automatic apparatus has not found favour in Great Britain. The final problem is to discover how small a quantity of excess air (which in practice has to be admitted) will ensure the complete combustion of the fuel, so that the flue gases may contain a high percentage of carbon dioxide. It is the carbon constituent of a fuel which, whether present as fixed carbon or in combination with hydrogen, *alone* burns to form carbon dioxide and therefore the higher the percentage of carbon the higher can be the percentage of carbon dioxide in the flue gases. The highest percentage possible is 21 per cent., because the air contains 21 per cent. oxygen by volume, and the percentage of carbon dioxide is always measured by volume.

If any of the carbon is displaced by hydrogen, oxygen, sulphur, or other constituent, as is the case with ordinary fuels, the maximum carbon dioxide which can be obtained will naturally be less than that which 1 pound of pure carbon would produce. Not even with the aid of their phlogistic theory could the alchemists convert a calx into the original substance by treating it with some material rich in phlogiston. Only carbon and oxygen can combine to form carbon dioxide, and the less carbon there is present in a given weight of any fuel, the less carbon dioxide can be obtained. It will therefore be realized that the maximum percentage of carbon dioxide which can be present when a fuel is burnt can be calculated from its chemical composition. It is very disconcerting to hear from some mechanic, who is very proud of his plant, that he maintains a constant high percentage of carbon dioxide, mentioning some figure which actually means that at times he must be recording more than the maximum theoretically possible.

The following formula, which may easily be worked out in a similar manner to that employed when finding the amount of air theoretically necessary for combustion, will give the maximum carbon dioxide which can be obtained:

$$CO_2 \text{ (max.)} = \frac{8{\cdot}88}{0{\cdot}425 + \dfrac{H - \frac{O}{8}}{C + 0{\cdot}37\,S}}$$

TABLE II.

R THE PERCENTAGE OF CARBON DIOXIDE OBTAINABLE WITH DIFFERENT FUELS.

Fuel.	Lowest Value.	Highest Value.
Coke	20·0	20·8
Wood	20·2	20·7
Brown coal	17·9	20·1
Peat	19·4	20·1
Bituminous coal	17·8	20·1
Anthracite	18·8	20·1

Table II. gives the maximum percentages of carbon dioxide that can be obtained with each of a number of fuels. When the maximum carbon dioxide which can be obtained has been worked out, the quantity of air supplied in excess of what is theoretically necessary for combustion will be equal to R in the equation

$$R = \frac{\text{maximum } CO_2 \text{ obtainable}}{CO_2 \text{ actually obtained}}.$$

Since the carbon in any particular fuel is combined with other elements in fixed proportions, the ratio is dependent on the excess air, reckoned in terms of its oxygen content.

The engineer-chemist of a firm which is a large consumer of coal and receives its supplies from a single source should have a sample of the coal very carefully taken, and have this sample analyzed to ascertain its chemical composition. Such a chemical analysis of coal is a lengthy process, involving very accurate work and, except in the rare cases where a skilled staff of chemists is attached to the works laboratory, the sample should be sent to a firm of analytical chemists.

It is of very great value to know the composition of a coal, for the following reasons:

1. The correct heating value can be worked out, and if the daily results of tests with samples of coal in the calorimeter in the firm's laboratory vary very much from the figure arrived at by analysis, it will be clear that either the testing methods are at fault, or—and this is more generally the case—the samples are not correctly taken.

2. The amount of air theoretically necessary for complete combustion may be calculated, and the engineer-chemist can work the boilers in such a way that the excess air supplied may be a minimum.

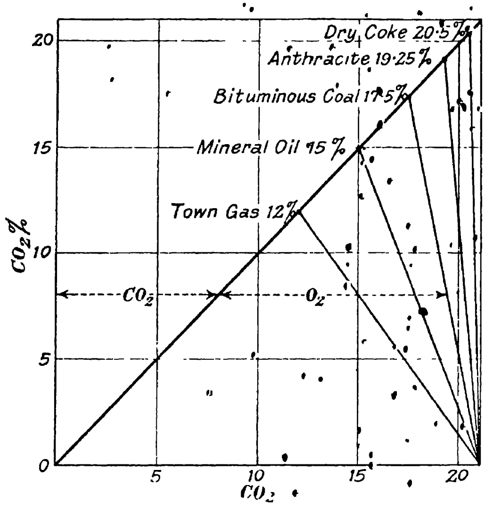

FIG. 9.—PERCENTAGES OF OXYGEN AND CARBON DIOXIDE IN FLUE GASES FOR DIFFERENT FUELS

3. The engineer-chemist—and this is most important—can work out the maximum carbon dioxide obtainable with the fuel, and therefore know exactly how matters stand by comparing this figure with the actual carbon dioxide as shown on the recorder.

Fig. 9 shows the extent to which the oxygen in the air supplied for combustion is converted into carbon dioxide. The maximum amount of carbon dioxide theoretically obtainable is 20·96 per cent., because the atmosphere contains that amount of oxygen by volume. For graphical representation this value has been taken as 21 per cent., and the vertical line represents the percentage of carbon dioxide in the flue gases. The horizontal line is graduated to show the composition of the flue gases in percentages of carbon dioxide and oxygen. The abscissæ of any percentage therefore meet at a point on the diagonal. A series of lines, each representing a special fuel, may be drawn from the right-hand corner to cut the diagonal at a point corresponding to the calculated maximum of carbon dioxide theoretically obtainable.

If all the oxygen supplied is converted into carbon dioxide, a horizontal line drawn through a point, the height of which is determined by the vertical scale, will pass through the point on the diagonal which denotes the maximum carbon dioxide obtainable. A horizontal line drawn at any other percentage will cut the diagonal. The distance between the vertical axis and the diagonal represents the carbon dioxide present, and the distance from the diagonal to the line representing the fuel under consideration indicates the unconsumed oxygen.

A chemical analysis need only be made when the regular source of supply is changed, or there is some reason to believe that a different quality of fuel is being supplied. To sign a contract for a year's supply of fuel, without any thought to the conditions that must be fulfilled to ensure its efficient combustion, is, however, to be guilty of inexcusable rashness.

In order to obviate the wastage of a large percentage of the heat content of coal through unskilled firing, various attempts have been made to supply fuel from which the volatile products have already been extracted. Examples of such modified fuel are coke and a large number of patent fuels, the most important of which is "coalite." Industrial coke is, of course, coal which has undergone a suitable modification process at a gasworks, so that practically only pure carbon and incombustible matter are left. Fuel of this character cannot make smoke, because the ingredients for making smoke are not present, and a loose fire may be kept which will allow the air to pass freely round the incandescent particles, and thus ensure perfect combustion. The air-supply can be regulated with greater accuracy, and a higher percentage of carbon dioxide be thus obtained without running any risk of inefficient combustion.

"Coalite" is the name that has been given to a patent fuel which is supplied for burning under the boilers of commercial power houses. It is prepared by a special low temperature carbonization process. The coal is not subjected to the high temperature usually employed in gasworks retorts when gas companies treat coal for the purpose of making illuminating gas, but is treated at a much lower temperature, so that the resulting fuel has a high calorific value compared with its weight, and yet retains sufficient volatile matter to enable it to be burnt with moderate draught.

The economy effected by the use of modified fuel is due to the separation of valuable oils, tar, and ammonia, each of which can be put to much more profitable use than consumption as fuel. There is also the advantage of smokeless combustion. Although the inefficiency will not manifest itself in the form of smoke, modified fuel may be burned just as wastefully as raw coal if unskilled firemen are in charge of the boilers, because, apart from the production of smoke, an excess of air above that actually required affects these fuels in exactly the same way as any other. The air-supply can, however, be regulated very much more easily, because the constant variation in the amount of inflammable gas which is given off when raw coal is used does not occur to any serious extent with patent fuels.

The remaining solid fuels of importance are the new formations of coal such as lignite, brown coal, and peat. These are not used very much in Great Britain, where there are but very small deposits of each, but on the Continent of Europe and in Australia brown coal and lignite are of great importance. Brown coal contains a very large percentage of moisture which may be as high as 62 per cent., but averages about 50 per cent. In a raw state brown coal is only used near the coalfields. It is generally dried and compressed by special machinery into briquettes, and in this form makes a very good fuel which can be burnt in a similar manner to coal. The object of converting the raw brown coal into briquettes is to escape paying freight on a large quantity of water which actually represents a loss in heating value. With average brown coal half the weight of the fuel transported would be water.

Lignite is very similar to brown coal, but does not contain so high a percentage of water. Although more efficient if first dried, it may, whether wet or dry, be burnt under ordinary conditions on special grates.

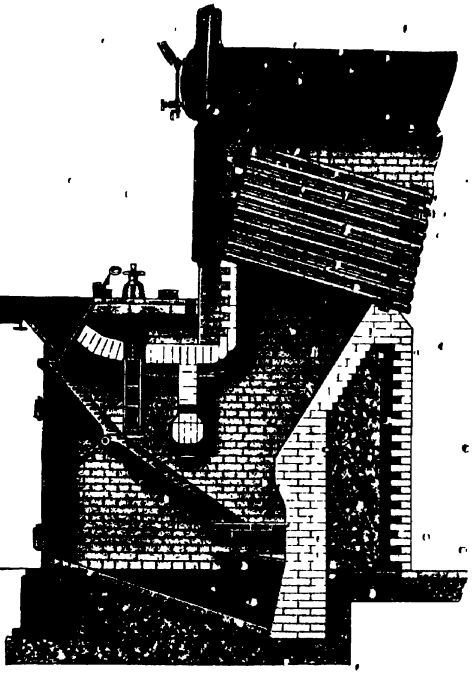

Fig. 10.—Babcock and Wilcox Boiler fitted with Stepped Grate and Special Furnace for Burning Lignite

The remaining fuels are of a miscellaneous character, and are represented by saw-mill refuse, lumber camp refuse (largely used in Russia), rice husks wet and dry sugar-cane, spent tan and town refuse. Most of these, with the exception of town refuse but including brown coal and lignite, are generally burnt on some design of stepped grate.

Fig. 10 shows a stepped grate built in front of a Babcock and Wilcox water-tube boiler arranged for burning lignite. The fuel is deposited on a raised platform and, according to its nature, fed through a large opening or small hopper, on to the grate. The thickness of the fire is regulated by a special door, which may be moved in a vertical direction. The design of the grate enables large volumes of comparatively bulky fuel to be rapidly consumed. The upper portion of the grate is so constructed as to allow a larger amount of air to pass through the green fuel and assist in burning the volatile gases. The slope of the grate gradually becomes less steep, so that although the volume of the burning fuel diminishes as it slips down towards the back by gravity, the bars will always remain covered because the angle of repose is reduced.

Reference should be made to colloidal fuel, although it is as yet rarely used. Colloidal fuel is liquid fuel in which very small particles of solid fuel are held in suspension. Some very successful experiments have been carried out on board destroyers of H.M. Navy, in which oil and finely powdered coal were burnt together. Further, recent developments have taken place in Sweden, where large quantities of fine sawdust have been burnt together with a small amount of oil fuel in a combined arrangement of solid fuel injection and pulverized wood.

(*b*) *Liquid Fuel.*—Very great progress has been made in recent years in adapting certain oils for steam-raising purposes. The adoption of liquid fuel, instead of solid fuel, has great advantages, but careful consideration must be given to the requirements of every case, and each must be judged on its merits. It is just as inaccurate to condemn oil fuel, when speaking of Great Britain, as it is to say that it is the best, and should be adopted universally. Oil fuel has great qualities, among which are cleanliness and ease of handling and storage. Increased heating surface is rendered possible by the absence of furnace fittings, and high efficiency is easy to maintain because the flow of oil is steady and because liquid fuel does not pass through stages of combustion requiring variation of air-supply. Its main disadvantage is high price regulated by a few companies. In a country like Great Britain, which has been endowed by Nature with large coalfields, a very strong argument can still be made for the continued use of coal. With oil fuel at present prices, it is folly to talk about its universal adoption as a fuel where coal, despite its increased cost, is still cheaper and—even more important—is already in the country.

There are certain cases, however, in which oil fuel can hold its own and has proved in practice to be more economical, as, for instance, in factories on the banks of large rivers and near an oil wharf, and in works, hotels, and other undertakings situated in the centre of large towns, where the gross cost of coal—that is, the cost of the coal from the time it is hewn till the boiler-house clinker has been disposed of—includes heavy charges for carting the clinker through the streets for delivery to some contractor or dumping into barges for conveyance to sea.

Ashore oil fuel is preferable only in special circumstances, but afloat the conditions are almost reversed. Large deposits of coal, where ships may re-bunker, have been established all over the world, and a large number of these depots are supplied with coal from Great Britain. It therefore happens that a ship, having rebunkered at a foreign depot on the homeward journey, actually arrives at a home port with a quantity of coals which originally left that same port. With liquid fuel the conditions are reversed. A ship will take on board a supply of oil at a foreign refinery, and this supply, due to the higher calorific value of the fuel in comparison with an equal volume of coal, will probably last until the ship can replenish the supply from another foreign source. The greatest asset this fuel possesses is that, being a liquid, it can be stored in the double bottom of a ship and not reduce the cargo-carrying capacity.

Fig. 11 is a section through a ship, from which it will be seen that the side-plating of a ship is single and is carried down under water to form the outer shell. Inside the ship, and riveted to the shell, is the upper plate of the double bottom, technically known as the tank top. The whole space between tank top and shell is divided longitudinally, that is, fore and aft, into water-tight tanks, and may be used for fresh water, for sea-water to serve as ballast and trim the ship, or, if desired, for oil fuel. During the war a large number of coal-burning ships laden with merchandise brought home oil in the double bottom, and thereby increased the tonnage available for transporting oil in bulk.

In the case of large Western ocean liners oil fuel has another advantage. The stay in port is regulated by the time these large vessels, burning thousands of tons of coal, require to fill their bunkers. The time lost in port is therefore an important consideration in view of the fact that the whole trip only occupies five days. The necessary quantity of fuel can be pumped on board in a very short time, and the return journey commenced. Moreover, an oil-burning liner requires many fewer firemen and trimmers than are needed on coal-burning boats.

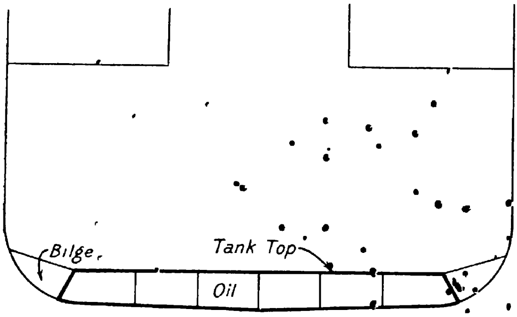

Fig. 11. Cross Section through an Ordinary Ship showing the Double Bottom

Fig. 12 is a view in one of the stokeholds of the T.S.S. *Paris*, showing boilers fitted with the Wallsend Howden liquid fuel-burning system.

The vital problem, from the point of view of economy, of supplying the correct quantity of air, can be solved much more easily under a system which gives a constant flow of oil to the burner at a given pressure than is possible when the quantity of air required for efficient combustion is continually changing, as in the case of coal-fired plants. For this reason boilers burning liquid fuel may be worked at a higher efficiency, because both the oil and air, when once regulated for a definite evaporation, need no further attention, whilst in the case of coal firing the human element is the deciding factor all the time.

Several systems of burning liquid fuel have been perfected. These systems may be divided into three classes:

Steam injection burners.
Air injection burners.
Mechanical burners.

The system generally found on board ships of the mercantile marine—the equivalent of the factory boiler house on shore—where profit is the first consideration, is the Wallsend Howden Patent Low Pressure System, which belongs to the third class, as given above. This system works as follows.

The oil supply on board ship is stored in the double bottom as described above, and because it is sometimes mixed with a small quantity of water the oil is first pumped into storage tanks in the stokehold and allowed to settle. The storage tanks are installed in duplicate so that the oil may settle in one, whilst the burners are supplied from the other. To facilitate separation, a heating coil is built into the tanks so that the oil may be heated to 170° F. Oil at this temperature will only take two or three hours to settle, and may then be drawn off with perfect safety.

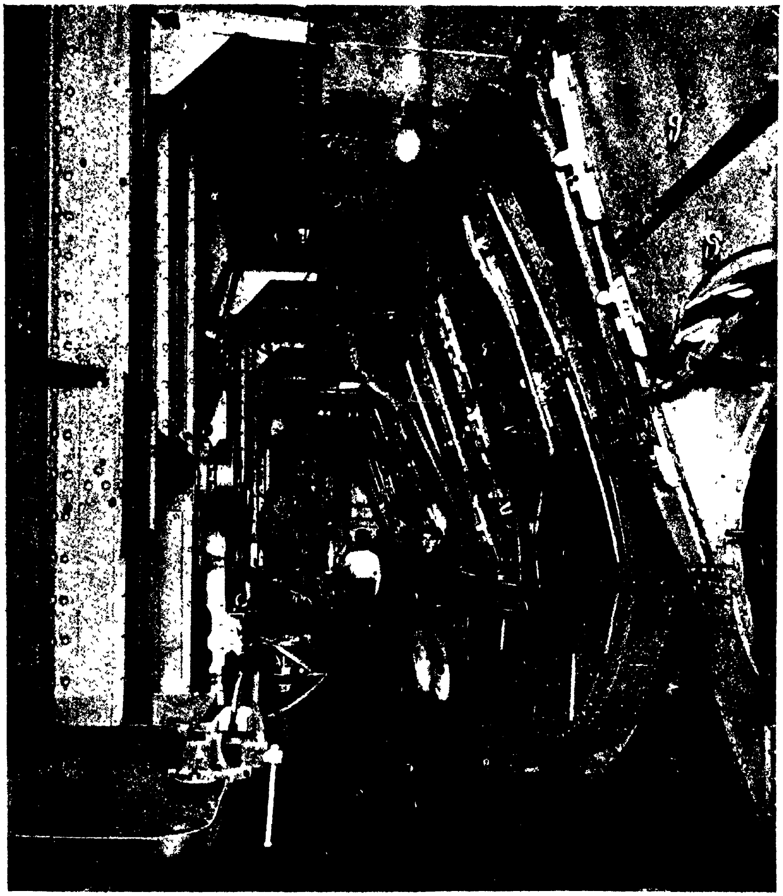

FIG. 12.—STOKEHOLD OF T.S.S. "PARIS," SHOWING BOILERS FITTED WITH WALLSEND HOWDEN LIQUID FUEL BURNING SYSTEM.

It then enters a special duplex suction strainer in order to remove any grit or other impurity that may be present. Thence it passes to the combined pumping and heating unit shown in fig. 13.

The oil enters the "Weir" simplex oil fuel pump through the inlet valve shown on the left-hand side attached to the pump, and leaves under pressure by the small pipe immediately above the inlet valve. It enters the heater by the valve shown. This heater consists of a large number of pipes bent in the shape of a ⊃, both ends of which are expanded into the same tube plate. This leaves the opposite ends free to expand, and eliminates the possibility of leaky tubes. The tube plate, which can be seen clearly in the illustration, is in the centre of the double joint.

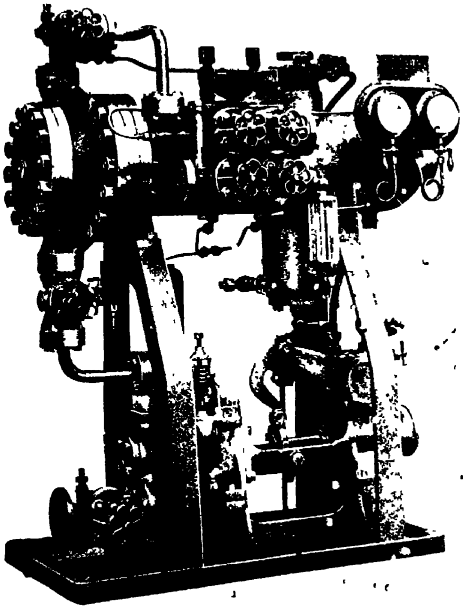
FIG. 13.—COMBINED PUMPING AND HEATING PLANT FOR WALLSEND HOWDEN LIQUID FUEL BURNING SYSTEM

The steam for heating the oil enters through the middle one of the three valves on the right-hand side of the heater near the pressure gauges. The left-hand valve is connected to the heater discharge valve, and supplies steam for blowing out the inside of the heater tubes and removing any oil deposit. The right hand valve supplies steam to the pump. The condensed steam leaves the heater by the small valve shown attached to the water collector.

The oil leaves the heater by the valve shown on the top of the heater on the left-hand side, and enters the duplex discharge strainer, from which it flows into the pipe which joins the flange shown on the left-hand side of the strainer, and goes straight to the burners.

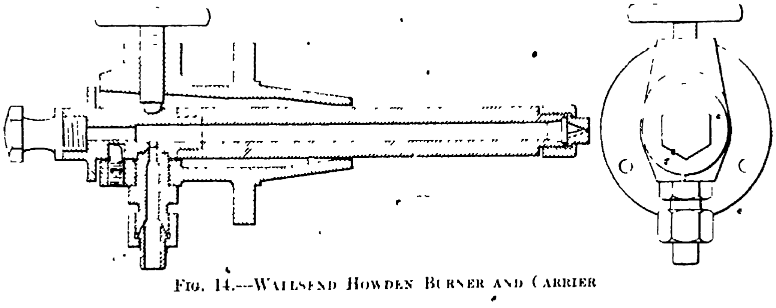
FIG. 14.—WALLSEND HOWDEN BURNER AND CARRIER

Fig. 14 shows the Wallsend Howden patent burner and carrier. This is so designed that the oil is forced into the furnace in the shape of a conical spray of exceedingly fine particles, and this, due to the temperature to which it has been heated, bursts into flame at a distance of but a few inches from the nozzle. It will be noticed that there is no valve in connection with the burner, the valve being in the pipe line between the burner and the supply main, and serving only to isolate the burner. The regulation of the oil supply depends entirely on the pressure at which the oil is forced through the nozzles, or, in other words, on the speed of the oil pump under the heater.

Fig. 15 shows the burner in position, and it will be observed that the complete furnace front is specially designed to provide the necessary air distribution for the efficient combustion of the oil. The oil fuel spraying nozzles pro-

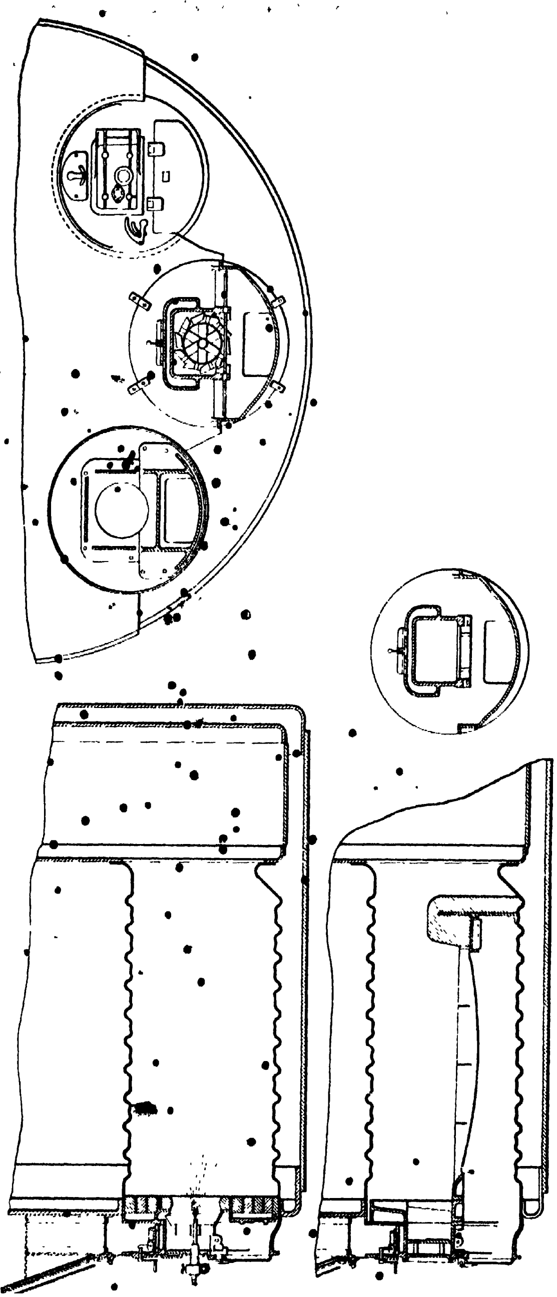

FIG. 15.—FURNACE ARRANGEMENT AS APPLIED TO A BOILER FITTED WITH HOWDEN'S FORCED DRAUGHT, SUITABLE FOR BURNING COAL ONLY OR LIQUID FUEL ONLY WITH FURNACE GEAR REMOVED

ject through a baffle plate or the front plate of the casing into an air trunk which receives its air-supply from a circular louvre attached to the front plate. This air trunk projects concentrically with a second air trunk carried by the furnace front, and the annular space between the inner and outer air trunks is fitted with deflectors constructed in such a manner as to give the air passing through the annulus a spiral motion. In cases where conditions warranted the adoption of oil fuel this system has also given excellent results on shore.

The first system in the list is the steam-injection system, so named because the atomizing of the oil is effected by means of a steam jet. This system is not so suitable for marine work because the steam used in spraying the oil is all lost, and the boilers must constantly be replenished with water, which means a large amount of "make up" feed water. As the amount of fresh water a ship carries in her tanks is limited, especially in the case of an oil burning vessel in which the oil fuel occupies space that would otherwise be available for water, an extra supply of the latter can only be obtained by evaporating sea-water. This, of course, is a costly procedure involving expenditure of fuel in order to obtain fresh water. On shore the water question scarcely arises, and the steam-injection system has therefore been introduced for ordinary working and as an emergency or auxiliary method of raising steam. It may also be used in connection with coal firing, as shown in fig. 16, to assist the latter during very heavy loads.

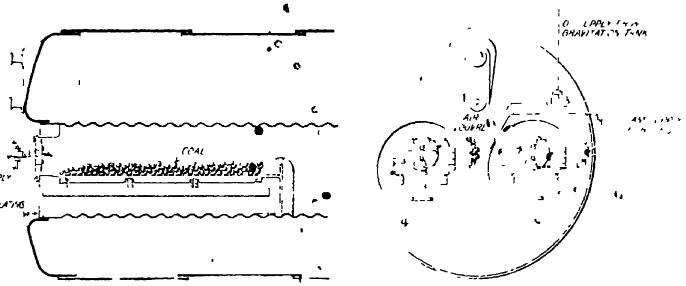

FIG. 16.—WALLSEND HOWDEN STEAM JET SYSTEM OF OIL BURNING AS APPLIED TO A LANCASHIRE BOILER WITH AUXILIARY FIRING.

The great advantage this system possesses when installed as an auxiliary or emergency method of raising steam, is that the initial cost of the apparatus is low, no expensive pumping units being required.

Fig. 17 shows the Wallsend Howden patent steam jet system of oil burning as applied to a Lancashire boiler.

The chief points requiring attention in connection with burning oil under boilers for steam-raising purposes are as follows:

1. The oil must be free from all water and solid impurities.

2. Before lighting a burner, pass air through the furnace to expel any gas remaining from previous firing.

3. Drip trays must be fitted wherever leaks are liable to occur, and a supply of sawdust should always be handy for sprinkling on any oil that may be spilt.

4. When lighting a burner always insert the torch before opening the oil valve. To open the oil valve first is to introduce explosive vapour into the furnace.

5. The oil must always be at a sufficiently high temperature at the burner to ensure rapid ignition.

When all the boilers are cold, and no steam is available either for driving the oil pump for the pressure system or vapourizing the oil in the steam-jet system, steam is generated in a small auxiliary boiler which is heated by means of a burner supplied with paraffin under pressure, the boiler feed pump and the air pressure for the burner being worked by hand. This is, of course, only necessary until steam has been raised in one of the boilers.

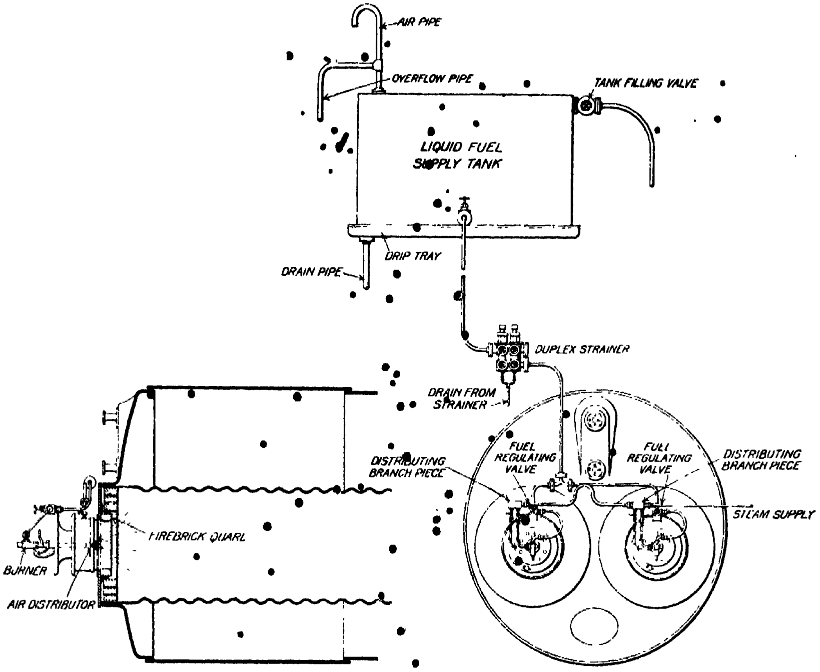

FIG. 17.—WALLSEND HOWDEN STEAM JET SYSTEM OF OIL BURNING AS APPLIED TO A LANCASHIRE BOILER.

(c) *Gas.*—The term "waste heat boilers" is employed in a very loose sense, and is often used to include not only boilers heated by gases of a high temperature, which are waste because combustion has taken place, but also boilers actually fired by so-called "waste gases," such as carbon monoxide, which is capable of further combustion to carbon dioxide. To the latter class belong all boilers fired with the waste gases from blast furnaces, and since the complete combustion of the gases has not yet taken place, these must not be confused with the real waste heat boiler. Waste heat boilers which are installed in order to utilize the surplus heat from blast furnaces, and which are fired with waste gas, should be classified with gas-fired boilers This gas may first be cleaned by installing a suitable gas-cleaning plant. That method is generally adopted, in which case the boilers are fitted with Bunsen type burners. In some cases, however, the unclean gas is used, and fig. 18 shows a battery of Babcock and Wilcox boilers arranged to burn waste gases from blast furnaces and provided with ordinary grates for auxiliary coal firing in case the supply of gas should be diminished or fail altogether.

Another source of waste heat from which steam may be economically raised is provided by coke ovens. When coke is made for use in connection with steel-making, the raw coal is treated by a quite different method from that adopted when coal is heated in retorts in the manufacture of towns' gas. Boilers can be installed in the former case for using a combination of waste heat and surplus live gas, the latter being burnt with Bunsen type burners.

In an up-to-date by-product coke oven plant, from every ton of coal carbonized 80 per cent of the gas will be delivered to the boiler in the form of waste heat, and the remaining 20 per cent in the form of live gas having a calorific value of about 175 British thermal units per cubic foot. Water-tube boilers, working in combination with coke ovens producing for steel works, have given an evaporation under normal working conditions of 1·25 tons of steam for every ton of coal carbonized.

(*d*) *Waste Heat* On account of the high price of fuel great attention has been paid to the utilization of waste heat, and great scope for the application of boilers heated by waste heat will be found in iron and steel works, in connection with reheating, puddling, and regenerative furnaces The essential feature of a boiler which is to raise steam by utilizing the heat in waste gases is a large heating surface compared with the volume of water which it contains In other words a very large volume of gas has to be dealt with in order to obtain the required heat and water-tube boilers are therefore especially suitable for the purpose

In some establishments the boilers are placed over the furnaces, whilst in others they are placed at the side or at the back. Water-tube boilers are generally used when the steam-raising plant is placed over the furnaces, and especially in the case of large reheating and double puddling furnaces, because a boiler must be adopted which has a very large heating surface compared with the ordinary Lancashire type. Space, however, very often does not permit of such an arrangement, and a smaller type of boiler must be employed Also, the volume of gas available may not be sufficient for even a small water-tube boiler In such cases vertical boilers have been used with very great success. Fig 19 shows a Cochran boiler heated with waste gas. Here, also, the fire-grate is retained so that the steam-pressure can be maintained when the heat contributed by the waste gases is not sufficient.

Waste gases leave puddling and reheating furnaces at a comparatively high temperature, and, as it is the practice to use blowers, the draught required at the

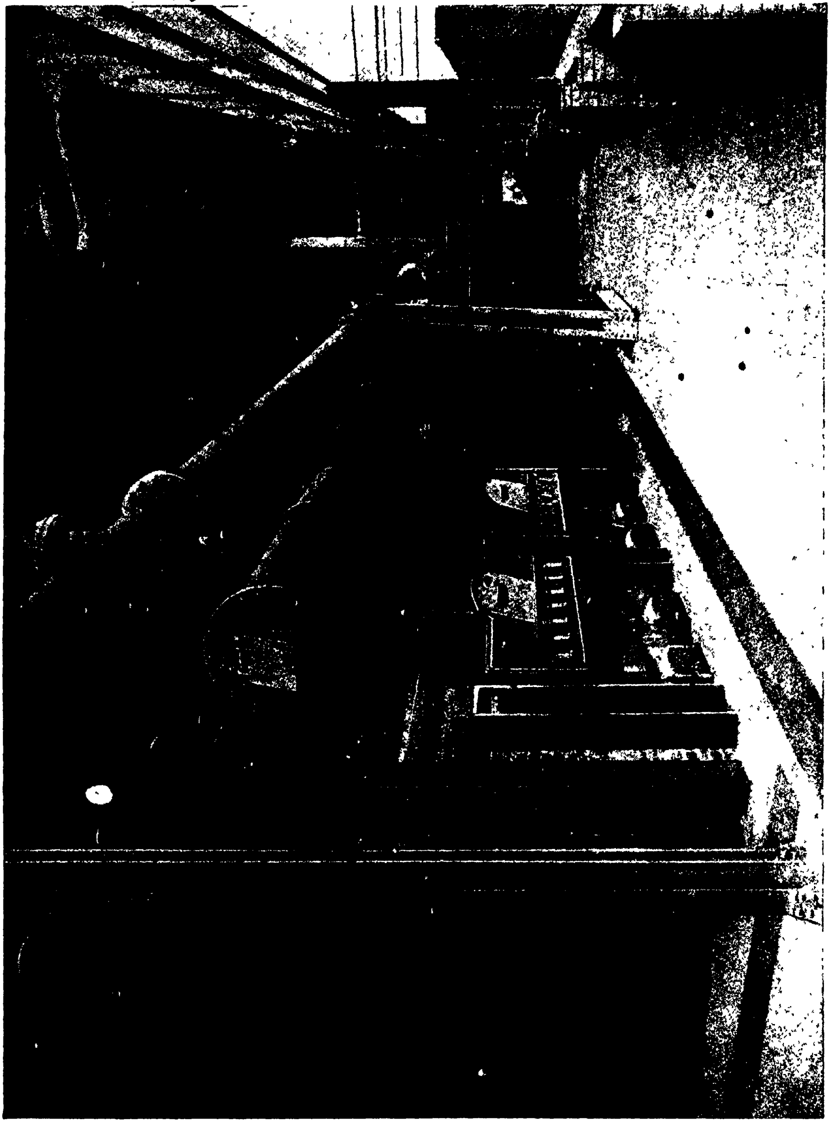

Fig. 18.—Babcock and Wilcox Boilers utilizing Blast Furnace Gas and arranged for Auxiliary Coal Firing.

furnace mouth is very slightly affected by the interposition of a boiler. In the case of regenerative furnaces the gases leave at a temperature of about 1160° F., and as a high draught is required at the furnace mouth special provision must be made to ensure that the draught at the outlet is not impaired. When installing a boiler under such conditions it is usual to include an induced draught fan to assist the passage of the gases through the boiler and leave the required static suction on the gas inlet side of the boiler.

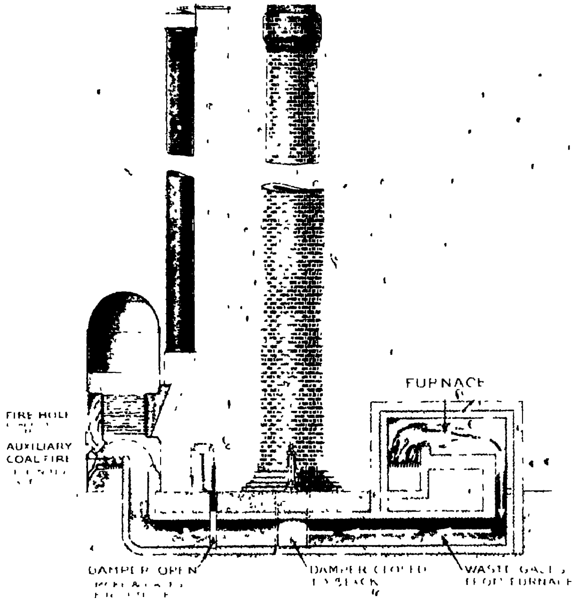

FIG. 19.—ARRANGEMENT OF FURNACE AND COCHRAN BOILER FOR THE UTILIZATION OF WASTE HEAT.

CHAPTER III

METHOD OF FIRING

(*a*) *Raising Steam.*—The method of raising steam depends entirely on the type of boiler.

We will consider first the ordinary Lancashire boiler. The great popularity of this boiler as a steam producer is due to its ability to withstand very rough treatment. When a Lancashire boiler has been cleaned and made ready for use it may be filled either by a hose pipe inserted in the top manhole or through the feed check valve by a separate pump, the latter method being impracticable unless there are two independent feed ranges.

Boilers are generally filled by hose pipe. The feed-pipe system in most cases is not in duplicate, and if the check valve on the boiler to be filled were opened under working conditions the pump would immediately hammer very badly in the absence of any back pressure.

If the boiler is to be filled by pumping the water through the feed check valve it must be done when the other boilers are full of water and the fires are banked—in other words, under conditions which prevail only when the machinery is not working.

In any case, when the boiler has been filled to the correct working level, the manhole should be replaced and the boiler closed up ready for operation. A small fire may be lighted and the side flue dampers slightly eased. The longer the time allowed for raising steam, the better for the boiler, because it takes some time before the large mass of cold water becomes heated, and therefore it is some time before the whole shell of the boiler is at the same temperature. Steam may be raised in a comparatively short time, but the various joints will suffer in proportion to the rapidity with which the temperature is increased. Under normal working conditions eight hours is the minimum that should be allowed for the boiler to become uniformly heated.

It is advisable occasionally to shut the water connection on the gauge glass and to open the drain, so that any pressure in the boiler due to the liberated air may be relieved. The cold water is often sluggish in coming to the right level in the glass.

Steam may be raised in water tube boilers, by virtue of their construction, with great speed and without damage. This type of boiler has a very positive circulation. The whole mass of metal being divided into small sections, a rapid uniform increase in temperature takes place. A water tube boiler is generally worked in conjunction with a closed feed system—*i.e.*, a condenser and air pump.

When a boiler has been filled with fresh water, which must, of course, be softened, special care must be taken to ensure that all the air liberated from the water may readily escape. This may be done either by opening the drain on the water gauge and closing the water cock every now and then, or the usual method—by opening the small cock fitted for this purpose. A third method is to slacken the small screw, whereby the pressure gauge may be drained, and to allow the air to escape through the pressure gauge pipe.

With boilers working on the closed feed system it is imperative to release all the air. If this be not done, corrosion trouble may be experienced later.

Scotch marine type boilers need very special treatment on account of their massive construction.[1] The shell plates are very thick, and therefore all joints are correspondingly massive. Consider, for instance, the joint where the flange of the front plate meets the circumferential shell at a joint in the latter. First there is the outside butt strap, then the boiler shell, then the flange of the front plate, and finally, the inside butt strap. Although the plates are scarfed and the total thickness of the joint not quite equal to the total of the thicknesses of all the parts just mentioned, very serious trouble soon commences if this joint starts to leak as a result of unequal expansion caused by forcing the boiler when raising steam.

Steam must be raised very steadily in marine boilers. In order to minimize the risk of unequal expansion when raising steam, the blow-down valves, which are always required by Lloyds and the Board of Trade to be in duplicate, consist of one screw lift and one non-return valve in the same casting, and are connected by means of a tee piece in the blow-down pipe range to the inlet side of one of the feed pumps. A small fire is lighted in the boiler, and the boiler blow-down and pump inlet valves are opened together with either the main check or the auxiliary (donkey) check valve on the boiler. The pump may then be started at an easy pace. The cold water is taken from the lowest part of the boiler and sent back through the feed check valve, which is, of course, placed as high in the boiler as possible.

When raising steam on a number of boilers, each must be "circulated" in turn for about a quarter of an hour, repeating the cycle until a temperature of 210° F. has been recorded by the thermometer in the pump discharge valve cover. The pump may then be stopped. Every part of the boiler being at a uniform temperature of 210°, little trouble from unequal expansion will arise.

When boilers have been standing a long time with banked fires, the same procedure should be adopted, because although the steam gauge may show 180 pounds per square inch pressure the bottom shell plate of the boiler may be stone cold.

Experience has proved that if the precautions indicated are taken when raising steam with this class of boiler, caulking tools need never be used from one year to another.

A boiler may easily be ruined by careless steam raising when quite new, and the damage will never be entirely rectified by caulking or any other method.

Attention must also be drawn to the very dangerous practice of tightening leaky joints when the boiler is under steam. This has been responsible for many fatal accidents. When steam is being raised on a boiler, before there is any pressure, the engineer-chemist should personally inspect every part of the boiler, with special reference to the manhole, and, in the case of water-tube boilers of the header type, the hand hole covers. The nuts on the manhole covers may be tightened a little, but when tightening them the men should stand clear of the manhole because one of the studs may snap. Cases are on record where the thread of the stud in the manhole cover itself was stripped, probably because the thread was partially corroded. In one instance a manhole cover was tightened up whilst the boiler was under steam, and the force of the steam on the stud, together with the extra tension caused by tightening the nut, blew the stud clean out, injuring one of the men.

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[1] *Manual of Marine Engineering*, A. E. Seaton.

If there are any serious leaks which cannot be stopped by slight increase in pressure whilst raising steam, there is only one right course of action. Allow the fires to die out, empty the boiler, and remake the leaky joint. Joints below the water level in the boiler can generally be detected whilst filling the boiler, and the flow of water can be stopped. If the leak is bad, due to faulty alignment of the manhole door or of the cap in a water-tube boiler, the flow of water should be stopped immediately. This will in all probability obviate the waste of much hot water. It is, of course, possible that the leak may "take up," but hopes based on that possibility will, more often than not, be disappointed.

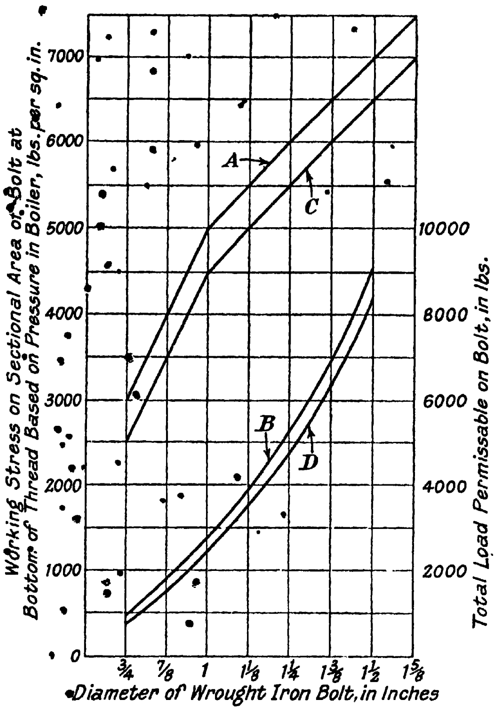

FIG. 20.—STRESSES IN MANHOLE DOOR BOLTS.

Fig. 20 shows the relationship between the diameter of a bolt, the stress due to the boiler pressure, and the total load permissible.[1] Curves A and C are for nuts tightened at a fortnight's interval, and curves B and D for nuts tightened every second day.

(*b*) *System of Firing.*—Broadly speaking, there are three methods of firing boilers which burn solid fuel—namely:

Hand firing.
Mechanical stoking.
Special methods (involving a combination of the other two).

[1] E. G. Hiller.

Most boilers are fired by hand, and, as always happens when everything depends on the human factor, the results obtained vary widely. The efficient utilization of any fuel, but especially coal, requires special knowledge. Because firing is not generally recognized as a complicated business, the prevailing standard of efficiency is low.[1] The different considerations which must be taken into account have already been reviewed in Chapter II, when dealing with the theoretical heating value of fuels and the quantity of air necessary for combustion. In practice the desired conditions are very hard to fulfil because the air actually necessary is constantly varying, and the hydrogen in the coal is, to a large extent, in chemical combination with the carbon. The volatile gases which leave the coal immediately a fresh charge is thrown into the furnace are all combustible, and to prevent their escape unconsumed several systems of firing have been introduced, viz.:

The coking system.
Sprinkling system.
Alternate side-firing system.

Coking System. This is the most economical way of firing a boiler by hand, but it requires considerable skill and entails harder work than the other two systems. Most hand fired boilers are worked on this system, but because of the skill and labour required the stoking is generally very imperfect and only a small percentage of boilers receive the full advantage of the coking. When properly worked the 'system' demands the use of the rake as well as the shovel and as very few firemen like working a rake the system fails.

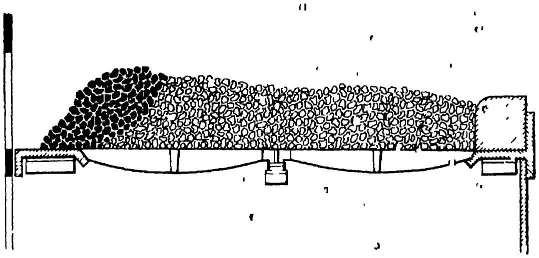

Fig. 21. Coking Method of Hand Firing.

Fig. 21 is a longitudinal section through a grate, and illustrates this method of firing. The green fuel should be thrown on to the front third or, approximately, the first two feet of the grate length. The heat of the burning fuel on the remainder of the grate causes the more volatile products, which make smoke, to leave the coal, and in passing over the bed of hot fuel these are ignited and consumed. When the heap of green fuel has partially coked the fireman should take a rake and distribute this fuel equally over the remaining two-thirds of the grate. The process is similar to the distillation of coal in gas retorts, only in the case now under consideration the gases are burnt whilst passing over the incandescent bed of fuel on the remainder of the grate, instead of being distilled.

By raking as described, the firemen keeps the grate always covered, prevents air leaks, and secures the complete combustion of the fuel, either in the first gas-forming stage or in the second stage, during which the pure carbon is burnt to form carbon dioxide. The usual habit of firemen is to shovel the green fuel on to the first part of the grate correctly, but not to take the trouble to use a rake to distribute some of this burning fuel over the grate at the right time. Instead, they use the shovel. The reach of the shovel is limited by its length and the intensity of the heat radiated from the fire, so that the back part of the grate is not properly covered with fuel, and one of the greatest air leaks in the whole boiler system takes place at the point where it can be most easily avoided. Low efficiency is the natural result. Occasionally a fireman will be found who has no leaks at the back of the grate, but he generally prevents leaks by throwing green fuel right at the back, which, of course, defeats the whole principle of the coking method of hand firing.

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[1] Prof. A. Smithells, British Association, 1907.

Sprinkling System.—The second method is the sprinkling system, which generally gives results as good as the more economical coking system just described, because the use of a rake is not essential, and the system is therefore worked more correctly.

Fig. 22 represents a section through a grate, and illustrates this system of firing. The green fuel is thrown over the entire area of the grate much as a man sprinkles sand on a slippery road, the whole secret being to throw the fuel evenly and very thinly. This necessitates frequent firing, the principle involved being that the gases given off during the coking process almost immediately burst into flame. The volume of the fuel thrown on to the grate at any one time is small, and therefore the heat required to ignite this mass being relatively small, the gases are burnt at once, and never get the opportunity to escape from the boiler as smoke.

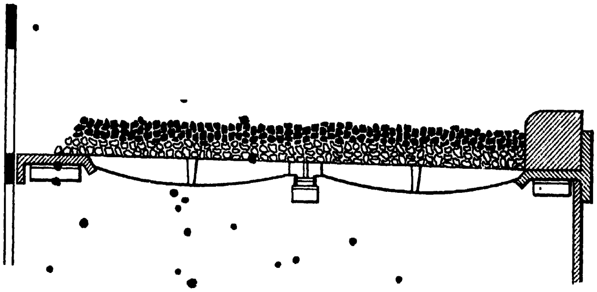

FIG. 22.—SPRINKLING METHOD OF HAND FIRING.

The risk with this system is that an unskilled or careless fireman does not like throwing a little fuel on the grate at a time, as it does not give him much " breathing space " between firing furnaces, and he therefore throws on shovelfuls at a time, with the result that the grate looks like a range of mountain peaks, and the furnace is of little use till the fuel has been given time to burn through. The heaps of green fuel will take some time to become ignited, but yet there will be sufficient heat to cause the volatile gases to leave the coal and escape up the flues as black smoke. When the fuel begins to burn through, the first places where the flame appears era between the heaps of coal, where the least resistance to the air takes place. At the next firing these places will be covered with fuel whilst the old heaps burn down, so that a good even fire is never obtained. As the heat is always sufficient to cause the volatile gases to leave the coal, but insufficient to ignite them, the whole thermal value of the gases is lost.

A rake should, of course, be used occasionally even when firing correctly by this method, as this will always assist the air to mix more freely with the burning fuel, and will stop clinkering as well as promote combustion.

Alternate Side-Firing System.—The third system, alternate side firing, is not much used in ordinary boiler furnaces. As the name implies, fuel is thrown alternately on the left-hand and right-hand side of the furnace at each firing, the assumption being that the green fuel on becoming coked falls down towards the centre. The middle of the grate therefore constitutes a channel of red-hot fuel, which burns all the volatile gases escaping from the green fuel lying banked up at the sides.

Fig. 23 is a cross-section through a furnace, and illustrates this system of firing.

The advantage of the system is that air leaks are not liable to occur so easily, and the furnace sides do not suffer so severely along the line of firebars, where corrosion is generally most prominent. The engineer-chemist should discover in which system his men are most proficient, and should adopt this as the recognized standard wherever possible. The nature of the fuel may not permit of this course, as some of the boilers may burn slack, whilst others again, which have heavier duties to perform, may even be fired with especially large coal.

In each case his aim should be as little smoke as possible, as smoke only denotes waste. A slight haze at the top of the chimney is most consistent with good practice. Complete combustion of the fuel, with no air leaks anywhere, is the goal of the engineer-chemist's ambition.

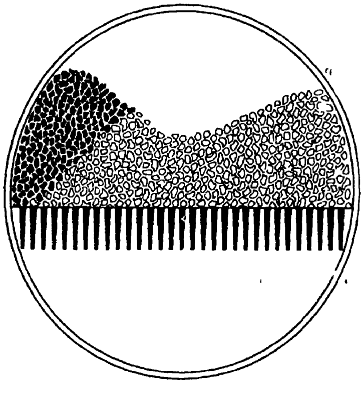

FIG 23 ALTERNATE SIDE METHOD OF HAND FIRING

The engineer-chemist will, of course, have to adapt himself to the type of boiler plant under his care, but the foregoing remarks are applicable in every instance.

In a large plant which consumes several thousand tons of coal per year a quantitative analysis of the fuel should be made twice a year, if the source of supply remains the same, and the result will be of great assistance when instructing the firemen how to burn the coal. Simply to make a guess and describe the coal as soft or hard, caking or non-caking, or in some other equally vague terms, is not consistent with scientific working.

MECHANICAL STOKING

Mechanical stokers have been invented in order to eliminate the human element as far as possible, and also to improve the conditions under which various fuels are burnt. Their most important advantages are continual supply of fuel and automatic removal of incombustible matter. With hand firing, every time a fresh charge of fuel is thrown on to the grate the furnace door must be opened, and this allows a large volume of cold air to rush into the furnace. Even supposing that the oxygen in this air combines with the volatile gases given off by the coal, there remains a large volume of inert nitrogen which has to be heated to the same temperature as the products of combustion, and therefore represents a distinct loss. With mechanical stokers no doors need be opened, because the fuel is passed direct on to the grate, and the excess air which may leak into the combustion chamber is not serious.

Another great advantage of mechanical stokers is that the fuel is handled by mechanical means, and more than one boiler may be operated by one attendant. The control of the mechanical stoker, and therefore the treatment of the fuel to ensure perfect combustion, still rests with the attendant, and in this respect the mechanical stoker is but a slight improvement on hand firing.

It is possible to obtain just as bad results with mechanically fired boilers as with those fired by hand. On the other hand, better results than can be obtained with hand firing are brought within the range of possibility.[1] A mechanical stoker, which is always supplied with fuel of the same size and of the same quality, heating value, and composition, may, if working under a boiler the load of which is constant, be so regulated that the results are above criticism. Under such conditions solid fuel is comparable with oil fuel in respect of the regularity with which heat is supplied to the boiler. Only rarely is efficiency of this high order attained.

Generally—and especially in large power stations—several fuels of widely differing character may have to be burnt. The bunkers, for example, may still contain some North Country coal when a new consignment of Midland coal arrives, and is added to the fuel already received. When the Midland coal begins to be used in place of that from the North Country, the stoker should, of course, be regulated accordingly.

The attainment of efficiency in combustion is conditioned by two factors: the rate at which the fuel is burnt and the adjustment of the supply of air according to the requirements of the fuel. The first may be controlled by regulating either the thickness of fire carried on the grate or the speed of the grate itself, by which is meant the rate at which the fuel passes from one end of the grate to the other. The air-supply depends on the regulation of the draught, a most important matter which will be dealt with in the next chapter.

If a high rate of evaporation is required a large quantity of fuel must be burnt, and this can only be done by carrying a thick fire and running the grate at a high speed. Every mechanical stoker is designed for the burning of a certain class of fuel with maximum efficiency, and it will be readily understood that if the fuel supplied differs widely from that for which the stoker was designed the results will be correspondingly unsatisfactory.

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[1] *Proc. Inst. Mech. Eng.*, D. Brownlie, p. 263, 1920.

In this connection a word may be said about the important influence of the ash content of a fuel.

Fig 21 shows the relationship between efficiency and the percentage of ash in a fuel.

Power-plant owners often make the mistake of supposing that quantity, and not quality, of fuel is the deciding factor in steam-raising efficiency. If, however, a fuel contains a high percentage of ash, then every pound of fuel on the grate carries with it a corresponding amount of incombustible matter, and in the case of hand-fired boilers the grate soon becomes clogged With mechanical stokers the incombustible matter is carried away by the grate, and the trouble with clogging does not arise, but the heat supplied to the boiler still remains low in proportion to the quantity of fuel used More fuel supplied also means more ash, and this may carry away considerable quantities of unconsumed carbon and of heat Although mechanical stokers are a distinct all-round improvement on hand-firing and the performance of modern power stations would be impossible without them, they will not of themselves ensure efficiency without supervision by a highly skilled engineer-chemist. The amount of skill required will vary with the duties required of the boilers and other conditions indicated in the course of the book. The boiler house of a factory which has to deal with a non-fluctuating load, and in which the coal supplied is always the same in every respect, enjoys ideal conditions, and the only regulation required will be starting and stopping, with the occasional use of a rake to touch up the front of the grate. Three distinct methods have been adopted in perfecting mechanical stokers for burning ordinary solid fuels, and these three methods are

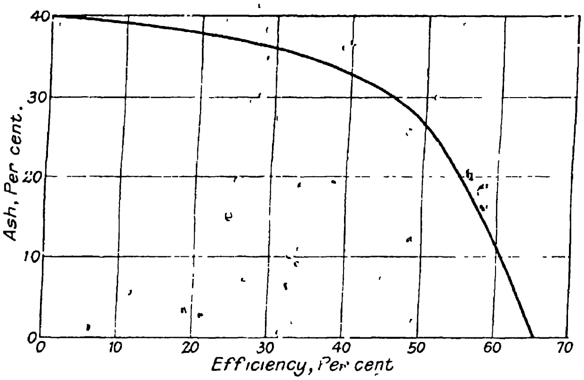

Fig. 21.—Relationship between the Ash Content of a Fuel and the Efficiency Obtainable

based on the same principles which govern their counterparts already described under the heading "Hand-Firing." The three classes of stoker are:

The coking stoker.
The sprinkling stoker.
The retort stoker.

Coking Stoker.—Nearly all mechanical stokers are supplied with fuel from overhead bunkers, the fuel falling by gravity through suitable shoots to the hoppers forming the front part of the stoker. In the coking stoker the thickness of the layer of fuel falling on to the grate is generally regulated by a door which may be moved vertically, and extends the whole width of the grate, so that an equal thickness and absolutely level bed of fuel is obtained. The period during which the bed of fuel retains this uniform thickness, which diminishes as the fuel passes over the grate, depends on the quantity of incombustible matter present, and on the resistance which the air meets in trying to pass through the fuel.

The speed at which the stoker is driven depends on the regulation of the stoker shaft driving gear, all modern stokers being so designed that the speed of the driving shaft is a constant.

The best-known example of this type is the chain grate stoker. The travelling grate carries the fuel very slowly through the furnace, so that by the time it reaches the ash plates all the combustible matter has been consumed and the ash and clinker fall into the ash pit.

Fig. 25 illustrates Babcock and Wilcox boilers fitted with patent open type chain grate mechanical stokers. The design of the stoker is such that the disintegration of the fuel is similar to that described under the coking method of hand firing. The fuel first undergoes a coking process, during which time it gives off the volatile gases which are ignited and consumed as a result of the heat of the fuel on the remaining part of the grate and the latent heat of the brickwork forming the lining of the boiler and the arches. The partially coked fuel is burnt during the next stage of the forward motion of the grate, and the remainder, generally pure coke, is consumed while the grate is in the back portion of the furnace. The incombustible matter is carried right to the end of the furnace, and finally falls over so-called "dumping bars," either into special hoppers, from which it is collected at regular intervals, or into a water trough conveyer.

Chain grate stokers are not fitted to narrow-flued boilers on account of the small space available, but in isolated cases a special type of Murphy furnace has been built in front of Lancashire boilers to accommodate the stoker. In such a case the boiler is, of course, not fitted with a grate. The general practice for this type of boiler, however, is to fit the moving bar and sprinkler type of stoker.

Sprinkling Stoker.—The sprinkling stoker works on exactly the same principle as the sprinkling hand-firing system already described. Fuel is projected on to the grate by means of a shovel which receives its impetus from a spring held under tension and then suddenly released, the tension and sudden release being the result of a revolving cam actuating the shovel mechanism. The shovel works in much the same way as a boy who splashes water by moving a board quickly forward from a vertical position to one approaching the horizontal.

It will be gathered that the distribution of the fuel depends on the power of the spring operating the shovel, and that this spring should therefore be carefully adjusted.

Fig. 26 illustrates the Bennis patent machine stoker, which is the best known example of this type. The fuel is first fed into a raised hopper in front of the furnace falls thence into a cast-iron feeding box, in the interior of which is a simple pusher

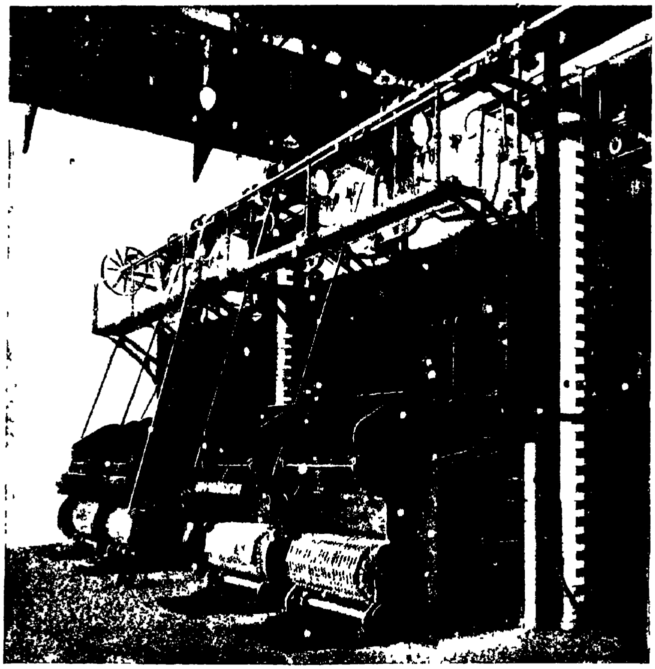

Fig. 25.—Babcock and Wilcox Boiler fitted with Open Type Chain Grate Stoker.

plate, and is pushed over a ledge formed by the bottom of the feeding box The weight of fuel so pushed over is regulated by means of an adjustable cam on the driving shaft, so that the rate of feed can be seen by noting the position of the cam The fuel falls on to a flat plate called the shovel box, and is projected into the fire at intervals by an angular shovel, being by this means effectually scattered over the entire width of the grate. The shovel is actuated by patent pneumatic gear, which consists of a long coiled spring enclosed in a cylinder and pressing on a piston, the use of the spring being to propel the shovel forward. The rotating tappet that

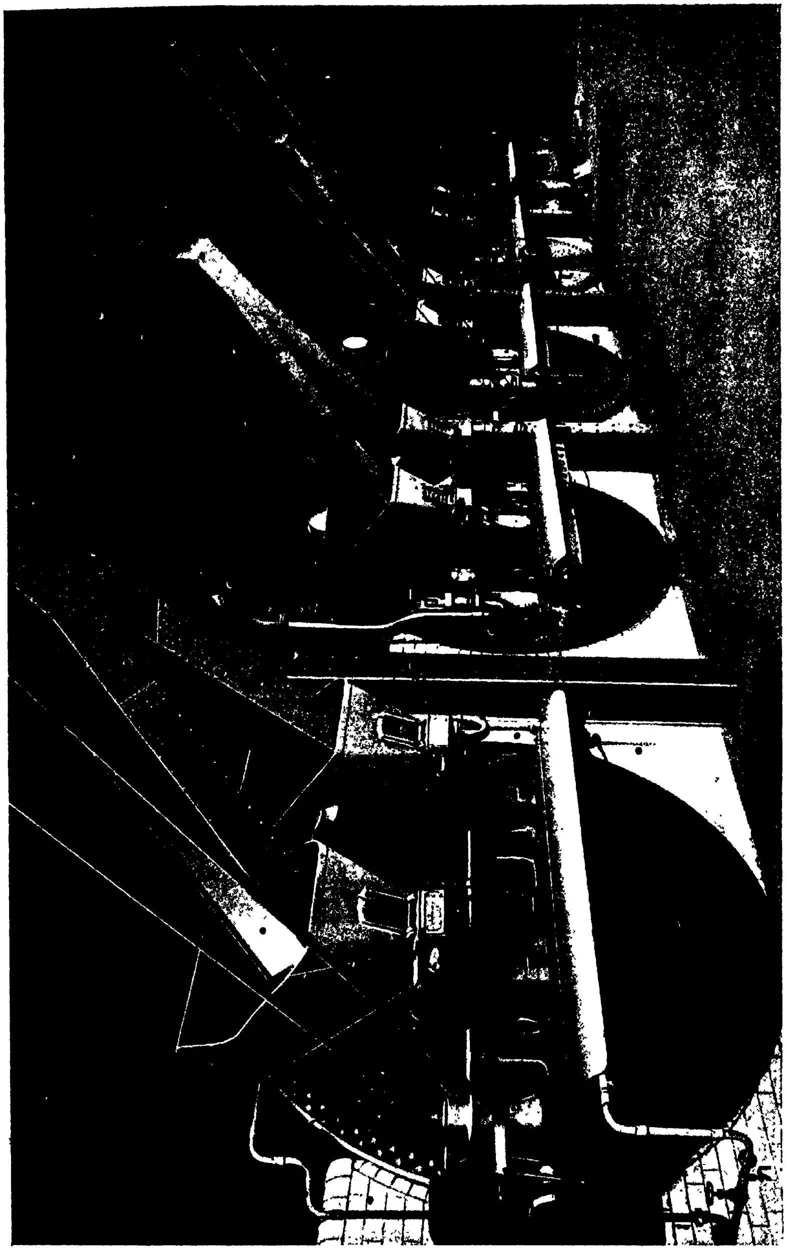

FIG. 26.—BENNIS SPRINKLER TYPE STOKERS AND COMPRESSED AIR FURNACES FITTED TO A BATTERY OF LANCASHIRE BOILERS.

draws back the shovel has four varying lifts. The effect is to scatter the fuel on the fire in four divisions, each about 18 inches long, so that in a 6-foot furnace the fuel is thrown on only a quarter of the fire at once. Each portion of the fire thus has time to become incandescent between the charges.

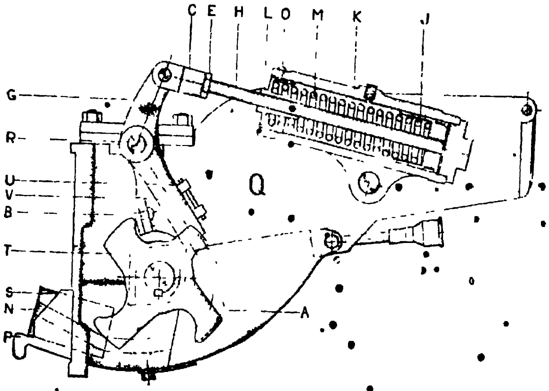

Fig. 27 Throwing Mechanism of the Bennis Machine Stoker

Fig. 27 shows the method of throw, being a detail of the shovel mechanism of the Bennis patent machine stoker. The shovel arm consists of an arm A with a pointed shovel S. This is attached to a lever arm G, integral with the rocking shaft R. The lever arm G is provided with a tripper B, and terminates at its upper end in a joint working in a cross-head C, which is connected to the rod H and works the piston J. A spring, M, pressing between the piston J and the end of the adjusting nut L, provides the motive power for propelling the shovel S.

This stoker is fitted with Bennis patent self cleaning compressed air furnace.

When using low-grade fuels, which generally contain a large proportion of clinker and ash, the air spaces in the firebars of ordinary furnaces soon become more or less covered or stopped up, and the fire suffers in consequence. Unless the clinker and ash are continuously removed from the fire, it is manifestly impossible to adjust the supply of air to secure perfect combustion of the fuel, and for this reason tubular fire troughs having the same length as the grate have been introduced to propel the fuel forward. The tubular troughs are placed close together, and are protected from contact with the fire by being covered with short interlocking grate bars about 2 feet in length. Projections are arranged at the sides of each grid to ensure a regular and even air space. Air is forced through the grids by means of fine pin jets of highly superheated steam, which blow the air into the tubular trough at a comparatively high pressure. The tubular troughs all move into the fire together for a distance of about 2 inches, and are withdrawn individually by means of 4-inch wide cams on a transverse shaft. The clinker is slowly carried by this reciprocating action to the back ends of the bars, and is dropped over into the lower part of the furnace, which is made air-tight by the half division plate under the grate. This division plate is opened by pulling the chain, shown in the illustration, when the clinker may be withdrawn in the usual manner.

Retort Stokers. The principle involved in the retort mechanical stoker may be compared with that of the alternate side-firing system. An example of this type of stoker is the Erith Roe three-stage combustion stoker shown in fig. 28.

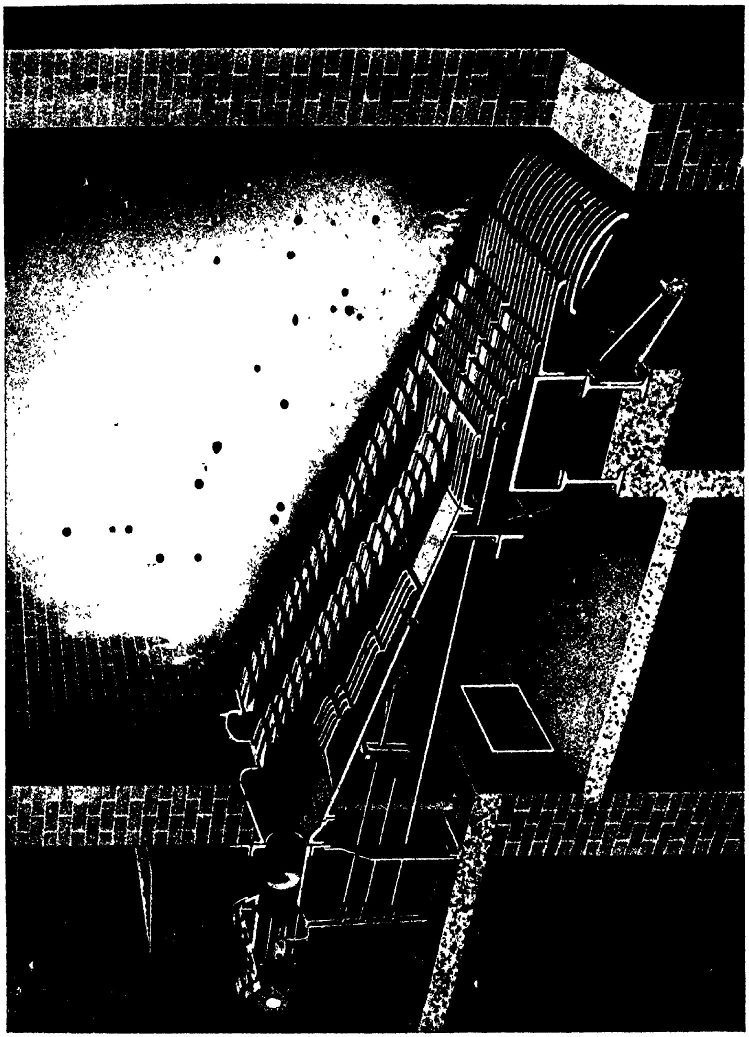

FIG. 28.—LONGITUDINAL SECTION THROUGH FURNACE SHOWING THE ERITH ROE SELF-CLEANING UNDERFEED STOKER.

The fuel is fed into the stoker hopper by means of gravity shoots from overhead bunkers as in the other systems, but it is then pushed into channels or retorts by the recurrent charging of the rams, which work in series corresponding to the relative positions of their crankshaft units. Adjustable stroke motions are transmitted by crosshead pins on each ram to a rocking lever, and thence by variable stroke rods to the pusher of each unit, to its extension grate section, and to the movable stepped hollow grate bars between the units. The pusher advances the fuel at its thickest section, distributing it outwardly over the stepped tuyers, and rejecting the incombustible matter from the zone of active or primary combustion The partly burnt fuel and refuse is subject to intermediate combustion as it travels down the stepped surfaces between the retorts, and any required degree of sliding motion is transmitted to the stepped hollow grate bars between the rows of fixed tuyers. The final stage of combustion extends across the entire width of the stoker, and adjustable motions are transmitted to the sectional extension grates at each coal feeding charge of the ram of each individual unit

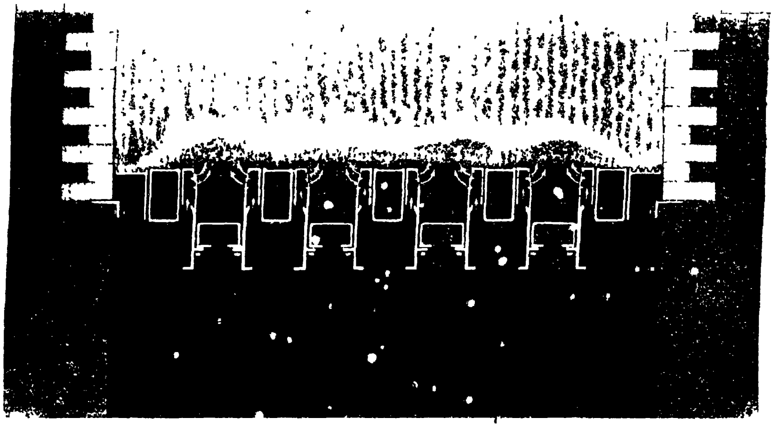

FIG 29 —CROSS-SECTION SHOWING THE FUEL BED ON A FOUR-RETORT ERITH ROE UNDERFEED STOKER

Fig 29 is a cross-section through an Erith Roe stoker and shows the fuel bed on a four-retort stoker. The stationary retorts are bolted at their upper ends to the cylinders of their ram sections, while the weight of the fuel bed together with the weight of the lower parts of the stoker is supported on base plates carried on heavy steel beams The tuyers are flat plate castings, bolted in stepped rows to their stationary retorts. The movable box-shaped grate bars alongside each row of tuyers extend from front to rear of the furnace The moving extension grate sections slide on the base plates Their recurrent motions are under entirely separate control from the motions of the pushers sliding on the bottom of the retorts The movable stepped grate bars are also independently actuated

This may also be seen in Fig 30, which is a section through a boiler fitted with an Erith Roe duplex stoker

The transfer of radiant heat from the incandescent surface of the entire fuel bed

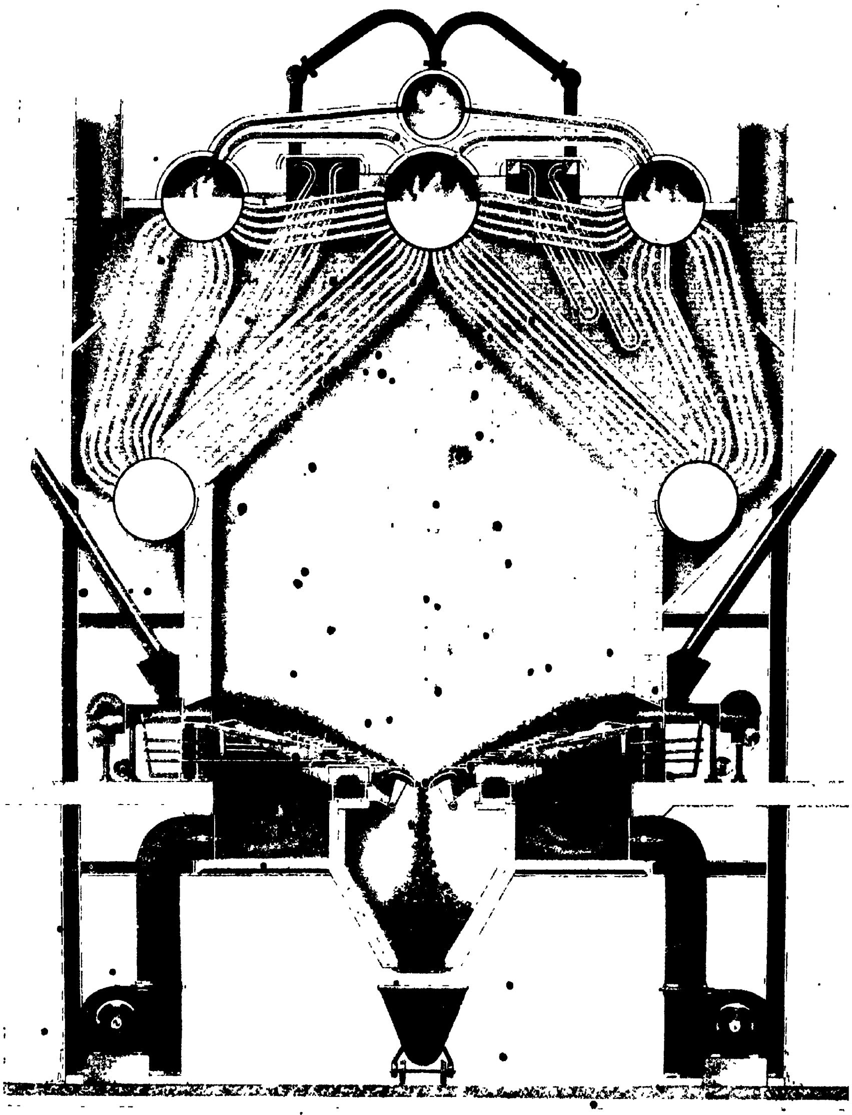

Fig. 30.—Section through a Boiler fitted with an Erith Roe Duplex Stoker.

on this stoker is instantaneous, approximately one-third of the total available heat being absorbed by the front banks of tubes before the gases come into actual contact with the boiler. This fact makes an undivided and archless furnace practicable, irrespective of the size of the boiler, because with radiant heat evenly diffused over the whole area of the front tubes internal deflecting arches are undesirable, and external coking arches are not necessary.

These stokers are very suitable for installing back to back, and with a duplex stoker as much as 250 tons of fuel may be burnt daily in a single furnace with a duplex arrangement of Stirling Tridrum boiler.

SPECIAL METHODS

Miscellaneous fuels are frequently burnt with a combination of hand firing and mechanical stoking. Such miscellaneous fuels comprise wood refuse, spent tan, sugar-cane, rice husks, and similar fuels which occupy a large volume and have a low heating value. On account of their bulky nature they are generally raised by a conveyor to a platform above the furnace.

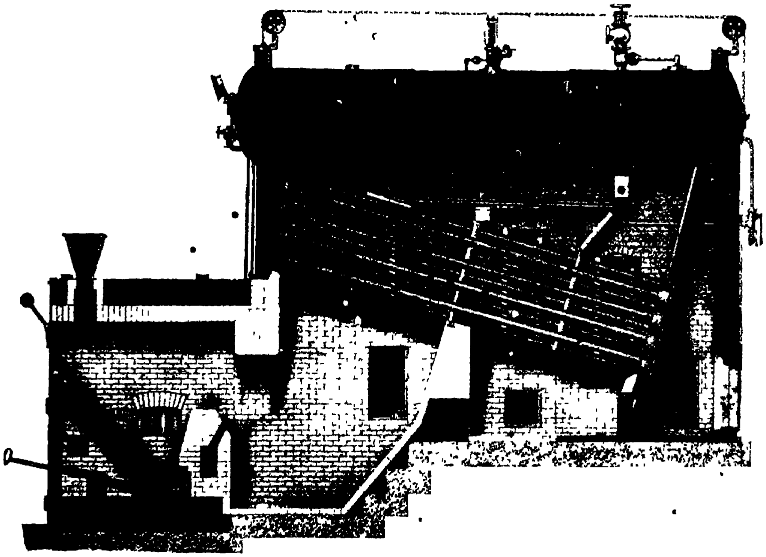

Fig. 31.—Babcock and Wilcox Boiler fitted with Superheater and Step Grate Furnace with Air-Heating Passages in Side Walls

Fig. 31 shows a Babcock and Wilcox boiler arranged for burning sugar-cane refuse. This particular design is adopted in Peru. Stepped bar grates are employed to burn bulky fuels, and the movement of the burning fuel is due to the action of gravity.

Fig. 32 shows a detail of a stepped grate stoker for burning wood shavings, from which it will be seen that the slope of the bars gradually diminishes to counteract the reduction in volume due to burning. In some cases, however, the moving bar type of grate has been very successfully employed. When burning fuel of this sort it is, of course, impossible to clean the grate, because the steam pressure would drop too rapidly while the job was being done. Some type of self-cleaning grate has therefore to be used.

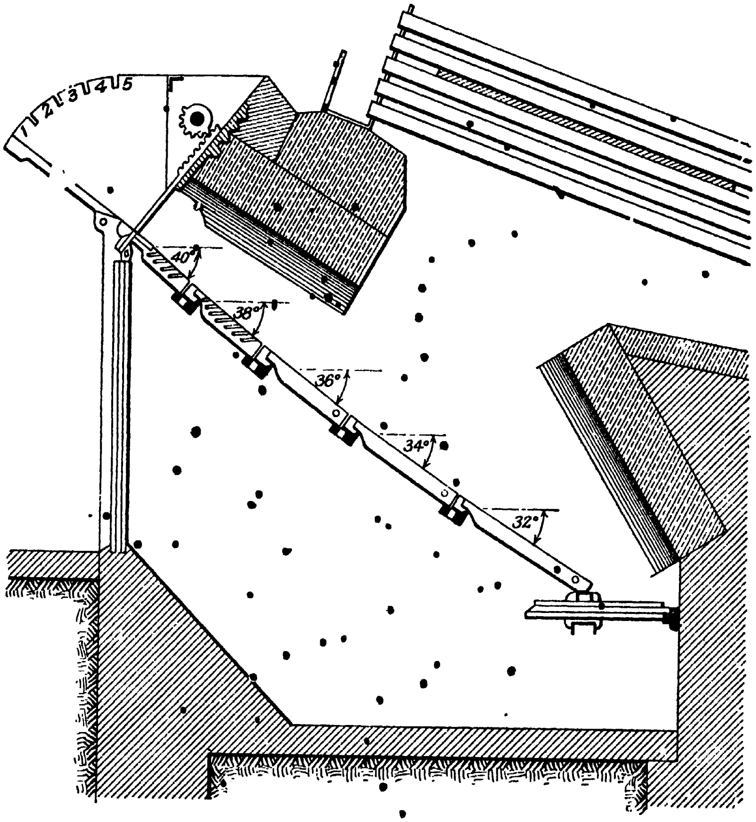

FIG. 32.—STEPPED GRATE FOR BURNING WOOD SHAVINGS.

The refuse from large towns can also be successfully burnt under water tube boilers for generating steam. Special furnaces are built for burning the refuse, and the water tube boiler is placed either above the furnace or at the side, so that the gases enter the boiler somewhat above the ordinary grate level. This enables auxiliary hand firing to be employed when desired—a matter of great convenience if the destructor plant is working in conjunction with an electric light station.

CHAPTER IV

REGULATION OF DRAUGHT

(*a*) *Hand Control.* The very great importance of regulating the exact amount of air required by different fuels has already been emphasized, but no indication has yet been given how this may be achieved. The methods adopted vary with the class of fuel to be burnt, and as it is quite impossible to describe all the apparatus that have been designed to meet special requirements, only a collective description can be attempted, with classification according to the system employed.

The air necessary for combustion should pass through the fire so that it may become heated in its passage and may also assist in keeping the fuel in a porous condition. When a fresh charge of solid fuel is thrown on to the grate, the volume of volatile gases escaping is very large, and the air passing through the bed of fuel will be at a minimum on account of the increased resistance. At the very time, therefore, when a comparatively large supply of air is required, the supply is actually decreased and the gases cannot mix with the oxygen necessary for combustion.

In view of this difficulty various methods have been devised to provide a "secondary" air supply, as it is called.[1] One method is to fit a sliding or rotating shutter to the fire door. This grid may be opened for a few minutes immediately after firing, but it must then be shut again. Most firemen have not been instructed in the correct use of this fitting, and either do not open it or leave it open, the result being in the latter case an excess of air all the time, which reduces the efficiency. It frequently happens that the shutters become very slack with wear, and continuously open themselves.

Another method of obtaining a secondary air-supply is to use a split bridge.

Fig. 33 shows a split bridge so constructed as to allow a certain amount of air, which can be regulated from the front of the boiler, to pass under the grate at the back of the boiler and meet the products of combustion as they pass over the top of the fire-bridge. As in the case of the sliding or rotating shutter, air should only be admitted for a short time immediately after firing. Seeing that most firemen neglect to work these fittings correctly, they are the cause of more harm than good, as they continually dilute and, therefore, cool the gases leaving the furnace.

Every time the furnace door is opened large quantities of cold air rush into the flues and reduce the temperature of the exit gases. On a large plant of, say, twenty Lancashire boilers, it may be said that one door is continually open. This cannot be avoided, but the firing should be done in a sharp and lively manner, and not in the leisurely fashion adopted by some labourers who can shovel coal, but are certainly not firemen. To a small extent the inrush of cold air may be retarded by choosing a suitable type of fire-bridge.

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[1] *Boiler Construction*, W. S. Hutton.

A very important factor, and one which can be relied upon to give results automatically once it has been given proper attention, is the correct spacing of the firebars.[1] The air space between the bars must be determined by the character of the fuel being burnt. The proportion of air space should be such that the maximum amount of fuel which may have to be burnt in order to cope with heavy demands for steam may be efficiently consumed.

For the ordinary Lancashire boiler grate the firebars should have an air space from $\frac{3}{8}$ to $\frac{1}{2}$ inch. but not less. In some cases Lancashire boilers have been fitted with mechanical stokers, which, in course of time, became worn, and were discarded. The patent firebars which formed part of the mechanical stoker were retained when hand firing was readopted. Naturally, the results are unsatisfactory, because a firebar which has been designed to work under conditions of mechanical firing can hardly be expected to give equally good service with hand firing.

Smoke is formed when the volatile hydrocarbons liberated from coal subjected to heat are not burnt. These will not be burnt if there is not sufficient oxygen in the air supplied to support their combustion, or if there is such an excess of air that it cools them below their ignition point.

(*b*) *Natural Draught.*—Most of the boilers attached to factories work with

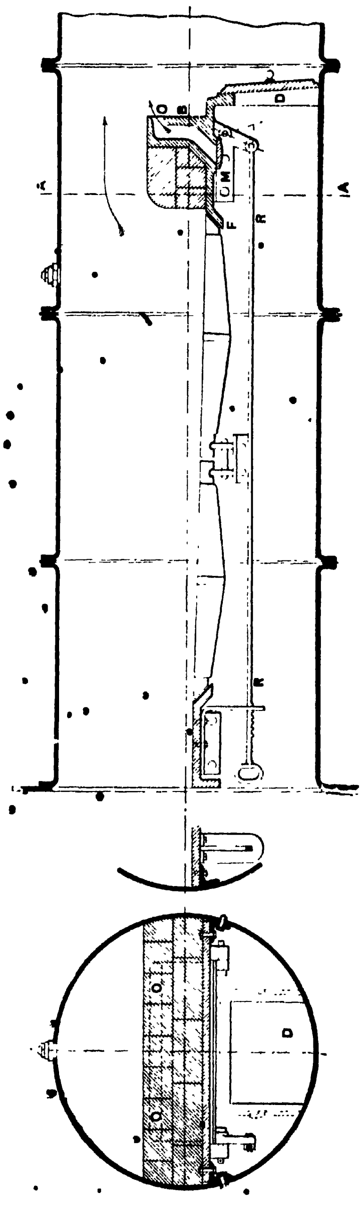

FIG. 33.—ARRANGEMENT OF A SPLIT BRIDGE FOR THE FURNACE OF A LANCASHIRE OR CORNISH BOILER.

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[1] *Smokeless Combustion*, D. T. Rondale, Washington, 1909.

natural draught—excluding steam jets for the moment from our consideration. The quantity of fuel which can efficiently be burnt, and therefore the maximum evaporation of which the boiler is capable, depends entirely on the draught available. Boilers which have a poor draught and are forced by offering the grate more fuel than it can consume are always the worst offenders as regards black smoke.

The draught available depends on the temperature of the gases, and the height and cross-section of the chimney. The hotter the gases the lighter their weight compared with that of the surrounding air, and hence the greater the speed with which they ascend the chimney.

Fig. 34 shows the relationship between height of chimney, mean temperature, and the draught in inches of water. The velocity with which the cold air rushes in

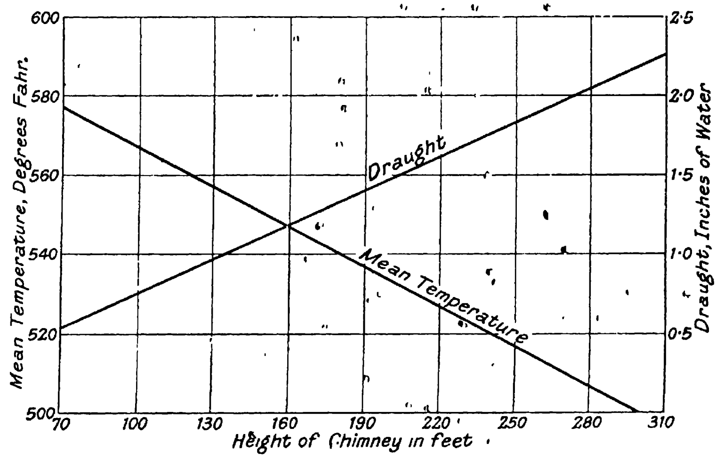

FIG. 34. RELATIONSHIP BETWEEN HEIGHT OF CHIMNEY AND MEAN TEMPERATURE AND DRAUGHT (IN INCHES OF WATER)

through the fire in the boiler is directly proportional to the speed of the gases ascending the chimney, assuming that there are no air leaks anywhere.

Fig. 35 shows the relationship between pressure in inches of water and the corresponding head and velocity of air at normal pressure. The velocity of gases in a chimney is roughly proportional to the square root of the value indicated by the water gauge, although the relationship is not exact, on account of the friction the gases overcome during their upward passage.

In view of the fact that the engineer-chemist will have to make use of the existing chimney, this matter need not be discussed further. The only contingency with which we are concerned is the regrouping of a number of boilers, which are served by two or more chimneys, into one power unit, when all the gases will be discharged into one chimney. In such a case the engineer-chemist will only consider the area of the chimney, and whether it is capable of acting as a discharge pipe to an induced draught fan which will probably be installed.

Most boilers working with natural draught can only carry a limited thickness of fire on the grate, because the maximum draught obtainable is not sufficient for a fire of the size which would best fulfil the requirements of the case.

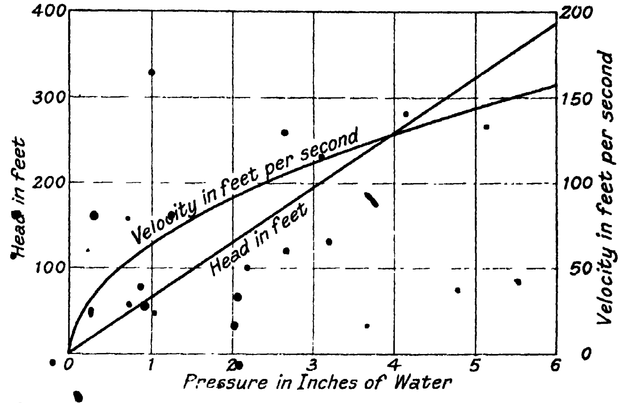

Fig. 35.—Relationship between Pressure of Air and the Corresponding Head and Velocity.

Air leaks due to faulty furnace fittings and cracks in the boiler brickwork, as well as in the flues, are very often responsible for the poor draught and consequent inefficiency of a plant. An ample supply of air through the grate is rather the exception than the rule, but, assuming the availability of an adequate supply, we must regulate it according to the kind of fuel being burnt and the thickness of the fire on the bars. This may be done by regulating the dampers in the side flues. The side-flue dampers should, therefore, be regulated from the front of the boiler. There are various devices for accomplishing this purpose. The simplest is to connect the dampers with balance weights by means of wire rope taken over suitable pulleys, so that the balance weights hang in front of the boiler.

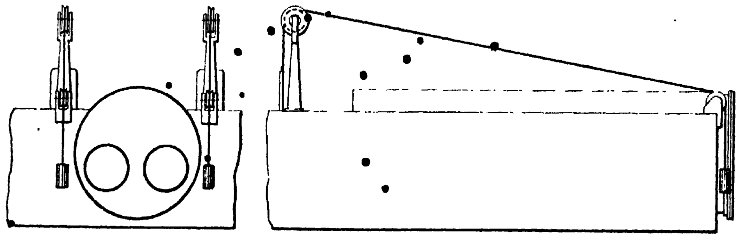

Fig. 36.—Method of Balancing the Side Flue Dampers of a Lancashire Boiler to facilitate Regulation from the Front End.

Fig. 36 illustrates such an arrangement.

On all boilers the dampers should be regulated from the front, whether the draught is good or bad, so that the dampers may be lowered and an inrush of cold air stopped, when fires are being cleaned.

Fig. 37 shows the arrangement at the front of a boiler burning coke. Not only is the supply of air more easily regulated on account of the absence of volatile

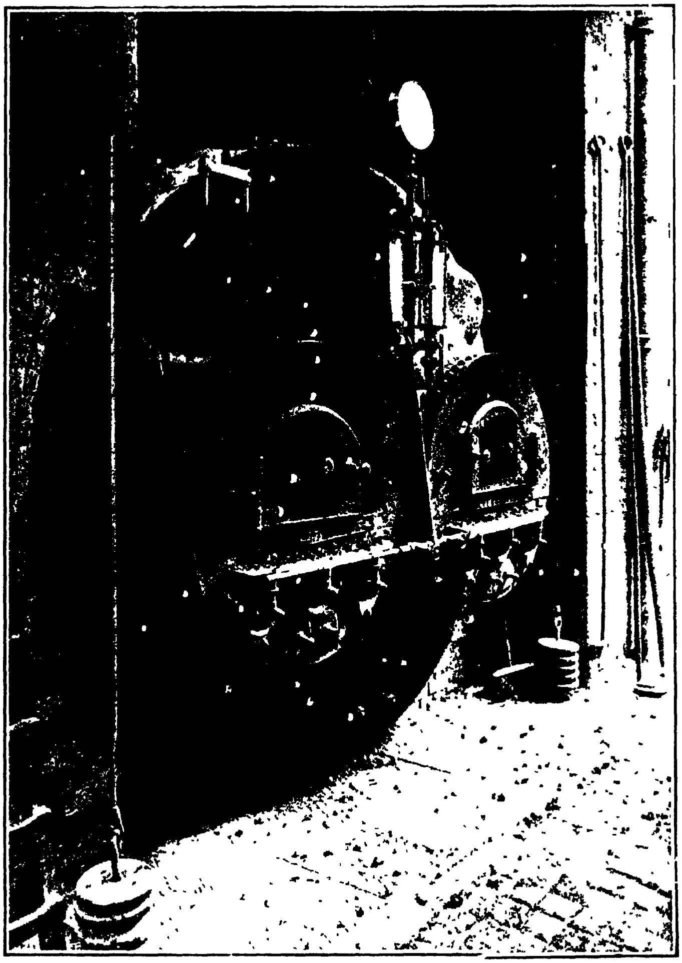

Fig. 37. Lancashire Boiler burning Coke and fitted with Side Flue Dampers controlled from the Front. An Ideal Combination.

matter, but by reason of the control of dampers when firing, the supply of air is never in excess, and a high average percentage of carbon dioxide can be maintained.

The foregoing remarks refer to the vertical drop type of damper generally fitted in the side flues of Lancashire boilers, but in the case of water-tube boilers a horizontal swivel damper is often fixed. The usual method adopted for controlling this type of damper is to key a grooved pulley, suitable for taking a chain, to the damper spindle, which projects some distance through the brickwork. The chain is led to the front of the boiler, passed over a second pulley similar to the first, and kept taut by some stretching device. A damper fitted with such an arrangement will be regulated by pulling the chain.

Whenever a swivel type damper is used as main damper (as, for instance, on board ships working with natural draught, in which case it is placed in the base of the funnel above the uptake), the lever attached to the damper swivel, or other regulating gear, must work in a quadrant. This quadrant must have two holes, so that by insertion of a steel pin the damper may be rigidly held in position.

Not very long ago, on a ship burning oil fuel with forced draught, the swivel damper in the chimney was displaced from the vertical or open position and, overbalancing, closed by itself. A serious back-draught was immediately set up, which burnt the men in the stokehold, several succumbing to their injuries.

With shore plants the main damper at the base of the chimney is generally of the vertical drop type, held in the open position by balance weights attached to a short length of chain. In every case where a plant suffers from back draught, or works with forced draught fans, this arrangement should be condemned, and a rigid method of fixture provided. The damper is very rarely shut, and in order to raise it to the open position, when it has been shut, it is an easy matter to rig up a block and tackle.

Another type of damper is the butterfly damper, in which the operating spindle is attached to one side of the damper. Such dampers are generally fitted in the economizer inspection passage in order to prevent short circuiting of the flue gases when the economizer is at work. In a small size they are often fitted in a horizontal position on top of flues to act as explosion doors.

The plates which are fitted to the ash pit of a boiler in order to deprive the boiler of draught are frequently referred to as dampers, but should not be confused with the types already mentioned.

All boilers require to be banked at times, and a small fire which may rapidly be rekindled has to be kept burning on the grate. This must not give sufficient heat to raise steam, but must yet maintain the required steam pressure. Common practice with Lancashire boilers is to regulate the side-flue dampers to obtain this result, but as these are never air-tight it is safer and more economical to reduce the draught by placing the ash pit covers in position. This remark has special reference to the banking of fires during the night. Should a sudden change occur in the weather, or direction of the wind, nothing can happen if the ash pits are closed, but serious damage may result if the side-flue dampers only have been closed.

(c) *Steam Jets.*—Steam jets placed under the front end of the fire bars are commonly used to increase the draught with Lancashire boiler installations. The arrangement of the jets varies very considerably—from 3 per furnace, that is, 6 per boiler, all situated at the front, to 10 at the front, 10 at the back, and 2 large jets inside the furnace over the fire, bringing the total up to 14 per boiler.

Some jets are supplied with saturated steam, whilst others work with superheated steam. In the latter case the steam pipe from the boiler is first taken a short distance into the side flue, and the return pipe leads to the front of the furnace and is arranged to take the nozzles. Such an arrangement is shown in fig. 26 (p. 51). Steam jets may work quite economically, using only 3 per cent. of the total steam evaporated by the boiler, but this is conditional upon the nozzles being new. 6·5 per cent. is the figure normally obtained in practice. The nozzles soon become enlarged by the scoring action of the steam, and the original pin hole may, in old nozzles, have grown to $\frac{1}{8}$ of an inch or more, in diameter. In view of the fact that the nozzles are very cheap and easily renewed, the prevalence of conditions like these is evidence of widespread carelessness.

Steam jets are of great interest, because the more steam is wasted in the boiler house the less there will be to pass on to the factory. The engineer-chemist must therefore keep strict watch upon the steam consumed by the jets, and renew these whenever necessary. Over the waste of steam in the factory the engineer-chemist may have no control, but for what is wasted in his own department he is responsible, and every engineer-chemist who wishes to "top the list" of departmental efficiencies will do well to give serious attention to this item.

Steam jets are often fitted to mechanical stokers suitable for narrow-flued boilers, in order to prevent the moving firebars from becoming overheated, and to give the air a high velocity when passing through the grate. They are also used with various types of patent grate for creating intense local draught, and in such cases they are often fitted at the back of the grate and force the air in a counter direction. Sometimes steam jets are built into the sides of brick combustion chambers in order thoroughly to agitate the products of combustion as they leave the fire, and to ensure that all the carbon monoxide is reduced to carbon dioxide.

Fig. 38 shows an ordinary steam jet nozzle, and indicates how the original pin hole may soon become enlarged.

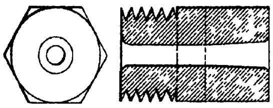

FIG. 38.—SECTION THROUGH AN ORDINARY STEAM JET NOZZLE WHICH HAS BECOME WORN.

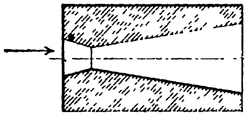

FIG. 39.—SECTION THROUGH A THEORETICALLY PERFECT STEAM JET NOZZLE.

Fig. 39 shows a section through a steam nozzle designed according to purely theoretical considerations. It will be seen that the cost of producing such a nozzle would be much higher than that of the type ordinarily in use. The shape is such that the slightest wear at the throat would produce results even worse than those caused by the ordinary nozzle when worn.

Fig. 40 illustrates a type of nozzle easily made in the workshop from good round bar steel. This is of such a length that even if the front end becomes worn the middle section will remain unimpaired for some considerable time. Nozzles thus constructed have given good results in practice.

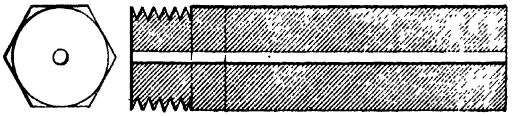

FIG. 40.—SECTION THROUGH AN ECONOMICAL STEAM JET NOZZLE.

On small plants burning wood refuse, apparatus similar to that shown in fig. 41 has been built into the base of the chimney.

This apparatus is very similar to the blast pipe fitted to locomotives, and can be worked either by passing exhaust steam through the smaller cone or by driving live steam through a small jet placed in the centre of the larger cone.

Wherever the steam jets are situated, and whatever their function, they are all liable to wear and to waste steam. The effect of using steam jets, especially when the coal contains a large percentage of sulphur, may be very dangerous, due to the formation of large quantities of sulphuric acid.

The supply of steam to the jets should be regulated by inserting a master valve and, where the boiler pressure is high, a reducing valve in the main supply pipe. Both valves should be of the lock-up pattern. In most cases the steam pipe is taken straight from the boiler, a small valve being fitted between the supply pipe and the front cross pipe carrying the steam jets. This valve often leaks as a result of being constantly opened and shut. Where there is no leakage from this cause it is usually because the valve is left full open all day long, thus wasting steam in another way. As it is the pressure of the steam, and not the quantity, which matters, an enormous steam value is wasted, representing hundreds of pounds' worth of good fuel burnt simply to generate steam which is blown *ad libitum* under the grate.

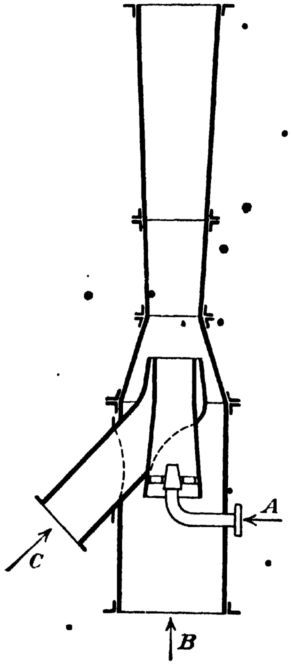

FIG. 41.—INDUCED DRAUGHT EJECTOR INSTALLED IN THE BASE OF A STEEL CHIMNEY.
A=Live Steam.
B=Flue Gases.
C=Exhaust Steam.

(*d*) *Fans.*—The most economical method of creating draught is by installing a fan, and such a fan may be used in connection either with forced or with induced draught. Forced draught has been adopted for marine work, but on shore it is, more often than not, found working in conjunction with induced draught, the combined system being known as "balanced draught."

Forced draught may be worked by two methods: either the whole space around the boilers may be under pressure, or only certain sections. The former is known as "the closed stokehold" method, and is practically confined to ships of H.M. Navy. The latter is that generally employed, and is called "the closed ashpit" method. In this case a constant air pressure is maintained under the grate, which is totally enclosed.

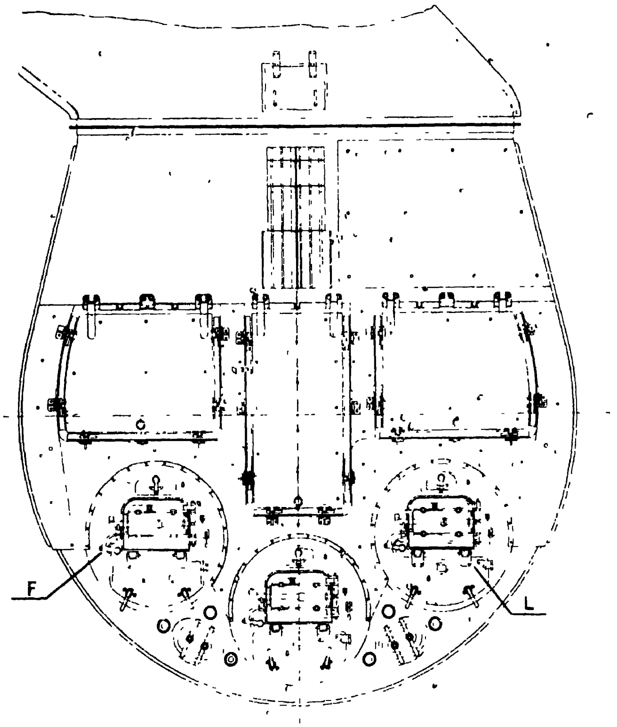

FIG 42.—FRONT VIEW OF MARINE BOILER FITTED WITH HOWDEN'S SYSTEM OF FORCED DRAUGHT.

The best known forced draught system is one which has been perfected by Messrs. James Howden and is extensively used in the mercantile marine. A fan, usually located in the engine room, delivers air through an air duct to a compartment on the front of the boiler and above the top row of tubes.

Fig. 42 is a front view of a marine boiler fitted with Howden's patent system of forced draught.

The compartment is fitted with a large number of short steel tubes held in a vertical position by a top and bottom tube plate. The air from the fan enters at the centre of the compartment and, passing round the tubes, becomes heated and escapes by air ducts on the right and left hand sides of the smoke box, finally entering the furnace front fitting. The furnace front fitting is provided with a valve which regulates the air supply and is so constructed that some of the air may be admitted above the grate whilst the greater part passes round an annular space and enters the ashpit. The furnace front being circular, its lower portion covers the front of the ashpit. Special air-tight doors are fitted to this lower portion, forming an absolutely air-tight seal.

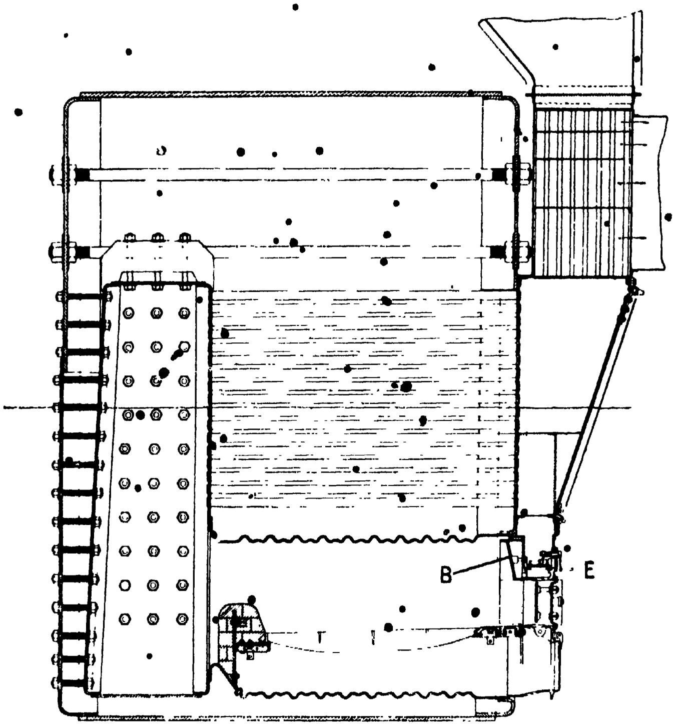

FIG. 43.—SECTION THROUGH MARINE BOILER FITTED WITH HOWDEN'S SYSTEM OF FORCED DRAUGHT.

Fig. 43 is a section through a marine boiler fitted with Howden's patent system of forced draught.

The products of combustion, on leaving the boiler, pass through the air-heating tubes and then away through the uptake and chimney. At the back of the grate is fitted a semicircular plate which is a tight fit in the lower half of the furnace, and the right and left hand fire bars are specially shaped to follow the corrugations of the furnace. Thus the whole grate constitutes an air-tight division between the upper and lower half of the furnace, except, of course, for the air spaces between the fire bars.

This is a very positive system of forced draught and, owing to the entire absence of any apparatus through which air might leak, the fuel may be burnt very efficiently, giving an intense white heat.

Forced draught on shore is practically confined to large mechanical stokers working under water-tube boilers, although there are some Lancashire boiler plants that work on very similar lines to those just explained.

When applied to water-tube boilers the principle of forced draught is much the same; the pressure fans are situated in the basement under the boiler-house floor and deliver into the air duct under the grate In the very latest practice this air is first heated, the fan discharging into a special heater above the economizer. In some cases a space has been left between the firebrick lining and the outer wall, and the air for combustion circulates through this space before entering the combustion chamber through the grate. When fuels, such as bagasse, inferior brown coal, or peat, which contain a large percentage of water, are being burnt, the increase in efficiency gained by pre-heating the air is very great, and with these fuels a large percentage of the air is sent into the combustion chamber over the grate The Erith Roe stoker already described is an example of the application of forced draught to boilers ashore.

Another example is given in fig. 11, which shows Babcock and Wilcox boilers fitted with that firm's chain grate stoker. The whole stoker is contained in an air-tight compartment, and the arrangement is known as the closed stoker. *Compare this with the open system shown in fig 25* When it is desired to burn a good-class coal containing a high percentage of volatile matter the doors are opened and the boiler is worked with natural draught or induced draught When a low-grade fuel is to be burnt the doors are shut, and the forced draught fan is set in motion.

Yet another type of forced draught mechanical stoker is the ordinary chain grate stoker which has been adapted to work with forced draught by fitting between the upper and lower chains a steel box into which air under pressure can be introduced.

Fig 15 shows a Babcock and Wilcox chain grate stoker adapted to work with forced draught. This is known as the compartment stoker The air pressure in each compartment can be varied at will to suit any condition of fire bed, and a slotted plate is placed over the top of the compartments through which the air for combustion passes. The slots are of a narrow gauge, and the air is forced through them at a high velocity. This results in a "blacksmith's forge action" being established, and consequently such fuels as coke breeze can be consumed at high rates of combustion.

The physical characteristics of fuel vary so largely that no rule can be given to determine when forced draught or balanced draught is necessary, until the calorific value falls below 9,500 B.T.U. Balanced draught is essential for fuels with a low percentage of volatile matter.

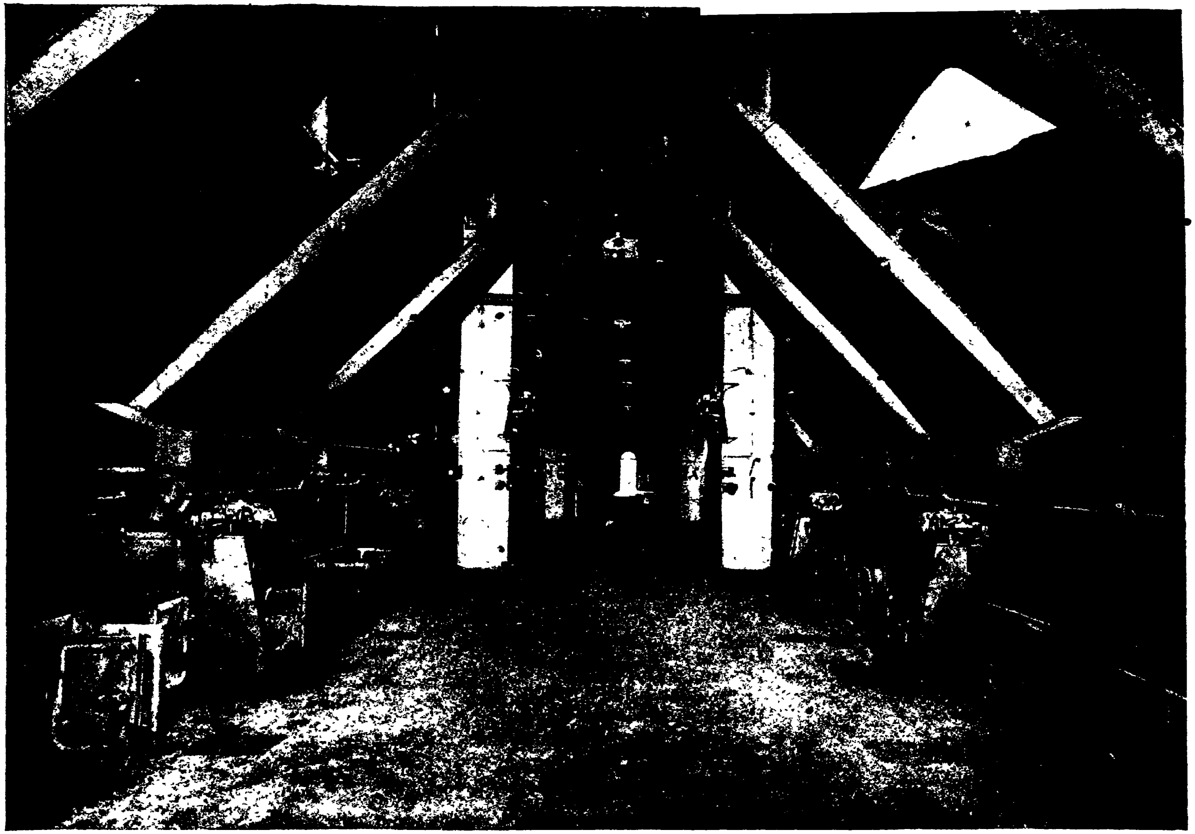

FIG. 44.—BABCOCK AND WILCOX BOILERS FITTED WITH ENCLOSED CHAIN GRATE STOKERS FOR WORKING WITH EITHER NATURAL, FORCED, OR INDUCED DRAUGHT.

The important item in connection with forced draught is to regulate the air-supply under the grate according to the different stages of disintegration the fuel undergoes. Assuming that the length of the grate is divided into four sections, the first section should receive a small pressure sufficient to ignite the coal. The second section should receive the maximum pressure, because on this part of the grate the combustion is most active, and all the air necessary to consume the volatile matter must be supplied. The pressure should gradually drop under the third and fourth sections, because the fuel bed is already thin, and consists of carbon and incombustible matter. Typical ratios might be 1 : 2 : $1\frac{3}{4}$: $1\frac{1}{4}$, but these will vary with different fuels.

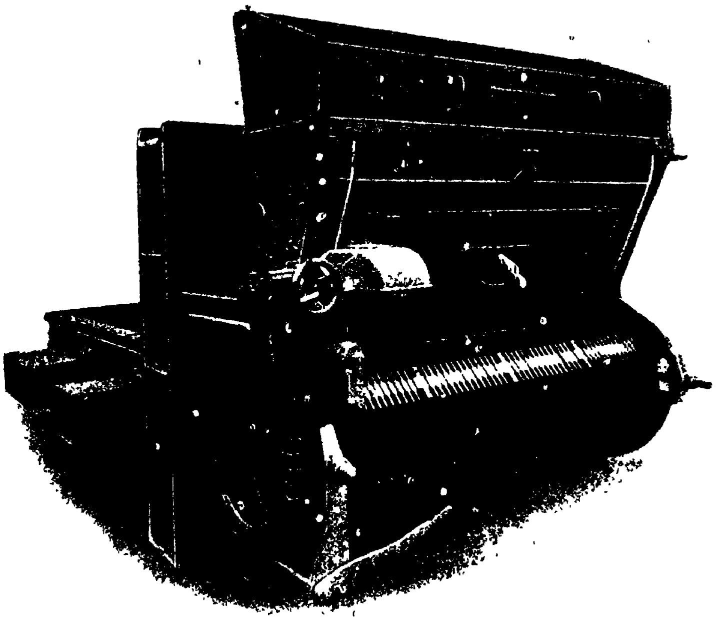

FIG. 45.—BABCOCK AND WILCOX COMPARTMENT CHAIN GRATE STOKER

Many mechanical stokers in large power stations are worked on the balanced system of boiler draught, and this calls for considerable skill in order to ensure correct manipulation. The duty of the forced draught fan is to supply the fuel with a sufficient quantity of air for complete combustion, and at such a pressure that the air may easily pass through the layer of fuel. The duty of the induced draught fan is to overcome the internal resistance of the boiler, and effectively to remove the products of combustion, so that the pressure in the combustion chamber may be equal to that of the atmosphere, thus minimizing the likelihood of air leaks. No heat is expended in creating draught, as in the case of natural draught, and when a boiler is fitted with an air heater it is claimed that the unit may be worked at 88 per cent. efficiency. A very wide range of fuels can be burnt efficiently with such an installation, because the flexibility of the arrangement allows a wide latitude, and the adjustments may be made with great accuracy.[1] These possibilities well illustrate the value of scientific control in a modern boiler house, and the extent to which efficient combustion of fuel has become a matter for the specialist.

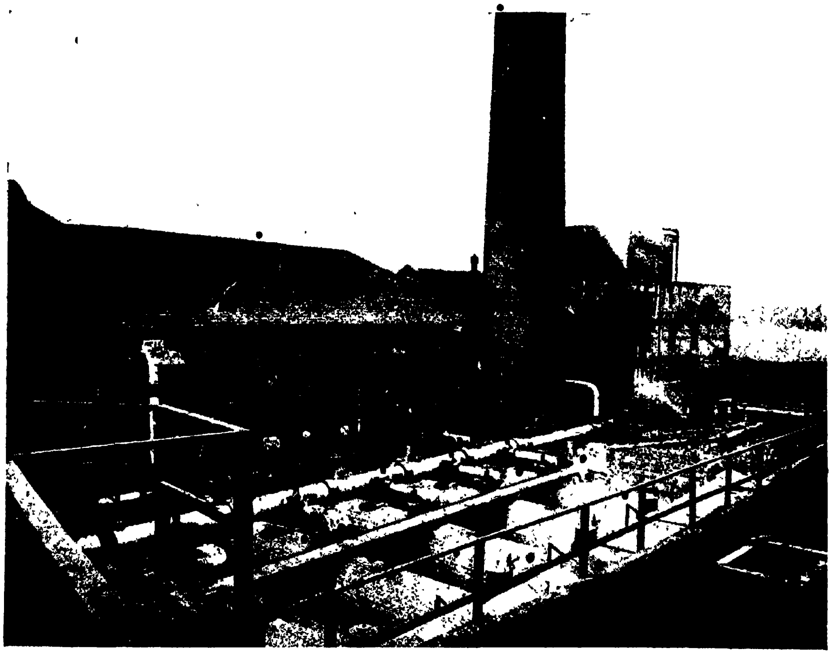

FIG. 46.—COLLIERY BOILER PLANT WORKING WITH A SIROCCO INDUCED DRAUGHT FAN.

Forced draught is rarely applied to ordinary industrial boiler plants, because of the skill required to manipulate the apparatus and the lack of proper methods of control in the boiler house. It is also an expensive business to adapt existing boiler plants to work under forced draught, but induced draught can be applied to almost any power plant whilst it is working, and the final connection to the main fl finished during a week-end.

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[1] Conference on Smoke Abatement, London, 1905.

Fig. 16 illustrates the foregoing remark and shows a typical colliery boiler pla fitted with a "Sirocco" induced draught fan. The conversion of an open-air boil plant of this description from natural to forced draught would necessitate su structural alterations that the saving obtained would not justify the capital outla

A forced draught fan is always smaller than an induced draught fan for the sa boiler power, because the former only has to deal with air the volume of whic changes very little with the difference between winter and summer conditions. Th variation in volume which occurs wit a fluctuation in the temperature of th flue gases is, on the other hand, ver considerable, and the induced draugh fan must, in addition, be able to cop with all the air leaks, which ar generally very numerous on an ordinary Lancashire boiler plant.

Fig 17 45 Inch Diameter Sirocco Induced Draught Fan, direct Coupled to a Sirocco High Speed Enclosed Engine

The induced draught fan should be somewhere near the chimney. Apart from distance, its position in relation to the chimney is quite immaterial, because the fan is capable of discharging the gases at a high velocity. The position of the fan with reference to the main flue or economizer outlet, if the latter be present, is more important. The fan should as nearly as possible draw through the centre of the main flue or economizer as the case may be.

Fig. 17 shows a "Sirocco" induced draught fan coupled to a high speed enclosed reciprocating engine It may justly be claimed for induced draught that the system will work quite well even where the passage of the gases has to be tortuous before they reach the fan. Fig 18 illustrates a typical case where a "Sirocco" induced draught fan has been mounted, because no other location was available, at the top of an economizer, and although the gases are subject to a vertical lift the performance of the plant is extremely satisfactory.

The method of operating an induced draught fan is to run the fan at a constant number of revolutions, which will be determined by experience, and to alter the side-flue dampers for fine adjustment. Every Lancashire boiler which is worked with induced draught should have an ordinary water gauge fixed at the front of the boiler and connected to the side flue. The pipe into the side flue should be not less than $\frac{5}{8}$ inch in diameter. It should be perpendicular to the flow of gas, and it should be situated near the side-flue damper. The connection to the draught gauge should be by means of a tee-piece and not an elbow, so that a rod may be inserted into the tube for purposes of clearing away any soot. Such a water gauge as is illustrated in fig. 49 may be made very cheaply by mounting an ordinary chemical **U**-tube on a board by means of clips and fixing a short scale graduated in eighths of an inch between the arms of the tube.

For boilers working with balanced draught it is necessary to provide a more sensitive instrument, of which there are many varieties on the market.

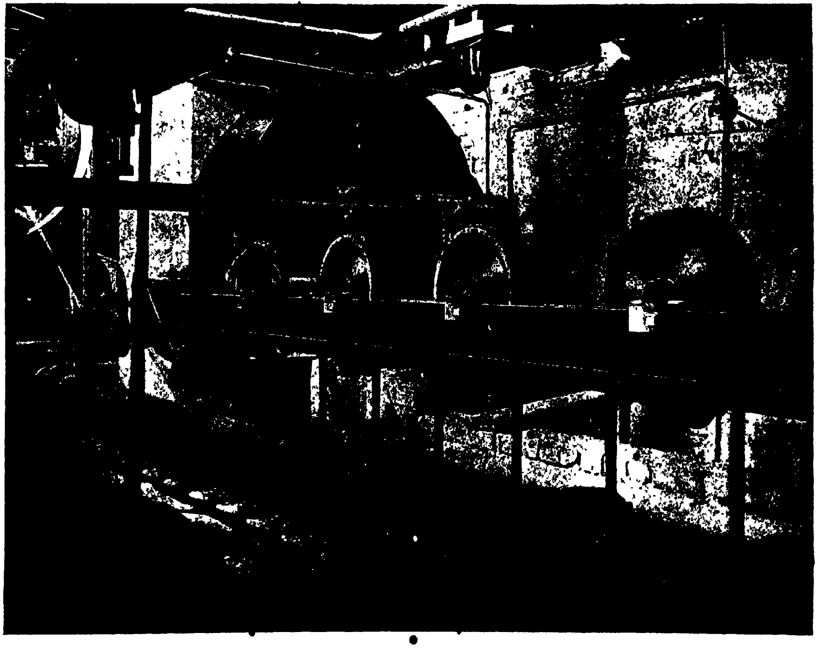

FIG. 48.—40-INCH DIAMETER SIROCCO INDUCED DRAUGHT FAN WORKING ON TOP OF AN ECONOMIZER

As an average working figure for a coal-burning Lancashire boiler, $\frac{5}{8}$-inch water gauge of draught in the side flues, with $\frac{7}{8}$ inch at the economizer inlet end, and $1\frac{1}{4}$ inch at the fan may be taken as correct, but no hard-and-fast rule can be laid down, as the regulation depends on the special circumstances of each case. The regulation will be affected by the nature of the fuel to be burnt, thickness of fire, layout of the plant, etc., and the requirements can only be met, in actual practice, by the engineer-chemist on the spot after he has carefully studied the various factors which influence the combustion of fuels.

The danger of inefficient working with induced draught is not greater than with any other system, although firemen, if not closely watched, will run the fan much too fast for economical working, because this will make their work easier.

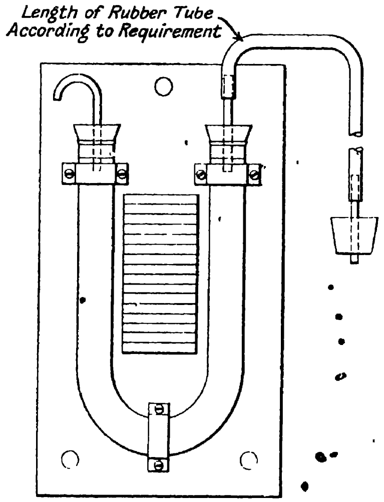

FIG. 49.—ORDINARY DRAUGHT GAUGE SUITABLE FOR A LANCASHIRE BOILER

Air leaks in the boiler setting and flues can very easily be detected with an ordinary hand lamp, and should be filled with fireclay or other suitable material until a permanent repair can be effected. In connection with air leaks and induced draught it should be mentioned that the additional air drawn in through cracks often assists in burning the volatile products after they have left the furnace. The admission of air in this way furnishes the correct explanation why some economizers actually produce a greater saving than one would expect. None the less, economies thus effected are very bad practice, because the flues will become overheated.

The great advantage of an induced draught fan is that a very short steel chimney — the minimum allowed by the local regulations—may be used instead of a lofty brick stack, with heavy foundations, which must receive the flue gases at a certain minimum temperature to create the necessary draught.

Fig. 50 shows a short self-supporting steel chimney which deals with the products of combustion from Lancashire boilers fitted with a "Sirocco" induced draught fan.

FIG. 50.—40-FOOT STEEL CHIMNEY DEALING WITH THE PRODUCTS OF COMBUSTION OF BOILERS FITTED WITH SIROCCO INDUCED DRAUGHT FAN

In the case of an induced draught fan the gases may be cooled down to their utmost limit. After passing through the economizer they should be about 210° F.

Fig. 51 represents the loss of temperature in the products of combustion between the grate and the chimney. The top curve A, shown dotted, is for a plant with induced draught, and the lower curve B, shown in full, is for a plant working with natural draught. It will be seen that with induced draught the initial temperature is higher and the exit temperature is lower, because no heat need be reserved for creating draught in the chimney, but all may be absorbed by economizers.

The power required to drive an induced draught fan varies from 0·75 per cent. in a large plant to 2 per cent. in a small plant of the total quantity generated, whereas the saving effected in the running cost frequently ranges from 15 to 20 per cent. This saving is the result of the fuel being more completely consumed in the furnace. In other words, a greater proportion of the value of the fuel is given up to the boiler, and the loss incurred by excess air reduced.

It has been stated that the *average* figure for the consumption of steam jets is 6·5 per cent., none of which is available for further use. Moreover, steam from the jets often causes rapid corrosion when in combination with flue gases containing a large percentage of sulphur dioxide.

Where a fan is driven by a steam engine, the exhaust can be condensed or utilized for heating feed water.

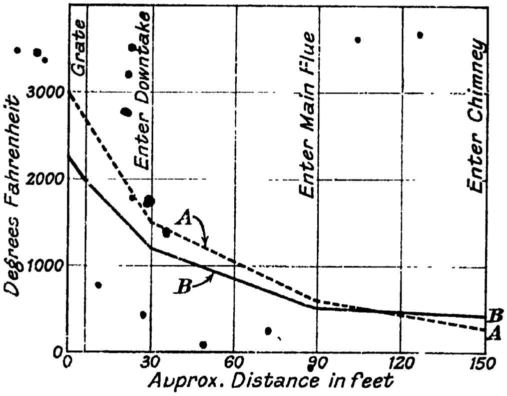

FIG. 51. COMPARISON BETWEEN TEMPERATURES OF GASES LEAVING A LANCASHIRE BOILER WITH INDUCED DRAUGHT (A) AND NATURAL DRAUGHT (B).

Of the total available heat generated by the fuel, 20 to 25 per cent. is carried away by the chimney gases, even in a boiler plant which is working under average conditions with flue gases containing about 8 per cent. carbon dioxide. If an average of 12 per cent. carbon dioxide with a temperature of 600° F. will reduce the losses to about 17 per cent., with further reductions still possible through a lowering of the temperature of the gases by the introduction of economizers, it is obvious that a very considerable saving can be effected by careful attention to the combustion of the fuel and the composition and temperature of the escaping gases. How important it is to keep down the proportion of carbon monoxide can be realized from the fact that the heat loss due to the formation of only 2 per cent. of this gas more than balances the gain due to the difference between 10 and 14 per cent. of carbon dioxide.

A further advantage of induced draught when applied to old boilers is that the steaming capacity may be increased, the available draught being quite independent of climatic conditions or the temperature of the flue gases, as already explained. A plant with five boilers, which under ordinary conditions can only just cope with the demand for steam, will, with induced draught, evaporate the same amount of water with four boilers, leaving one as a reserve The fact that thicker fires can be carried

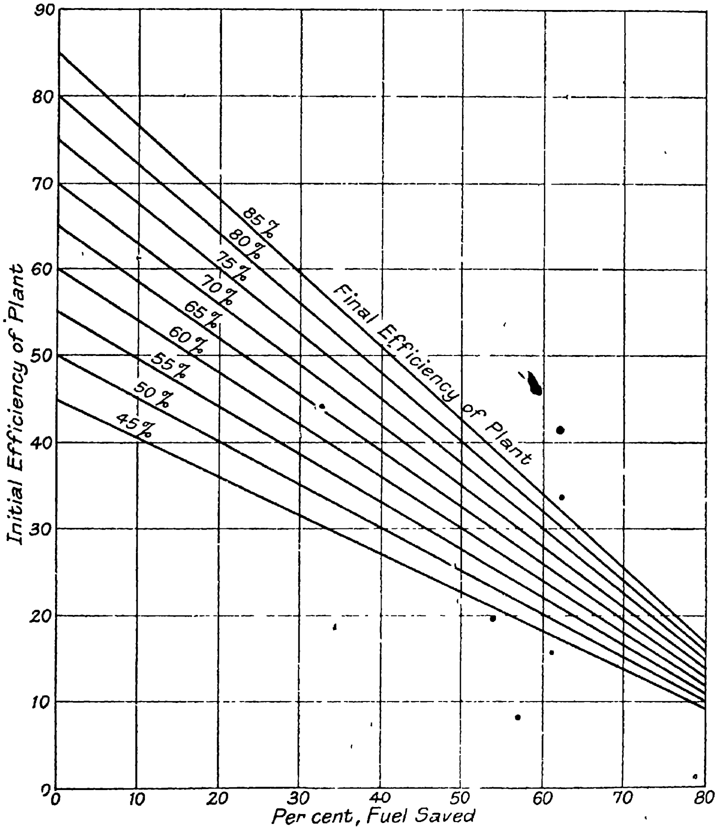

FIG 52 - PERCENTAGE OF FUEL SAVED BY INCREASING THE EFFICIENCY OF A BOILER PLANT.

with no air leaks in the grate will, with proper operation, raise the percentage of carbon dioxide, and an all-round increase in efficiency will take place [1]

Fig. 52 shows the percentages of fuel saved by increasing the efficiency of a boiler plant in various ways.

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[1] *Journal Royal Sanitary Institute*, vol xxxvii

SECTION II.—ATTENDING TO AUXILIARY APPLIANCES

CHAPTER V

SUPERHEATERS

THE temperature of saturated steam corresponds to the pressure, and because the pressure at which a boiler can be worked is limited by structural considerations, the temperature of saturated steam is also limited. Boilers are under construction or already working at 1,000 pounds per square inch pressure with a total steam temperature of 700° F. (saturation temperature 547° F.), but such apparatus must as yet be regarded as experimental. In order to overcome the difficulty of limited temperature, a superheater has been added to the power unit. A superheater is a piece of apparatus by which the temperature of steam may be increased, after it leaves the boiler, without increasing the pressure. The efficiency of any steam engine, considered as a heat engine, may be increased by raising the inlet temperature of the steam. The outlet temperature is more or less fixed and, as a result of modern improvements for maintaining a high vacuum, may be considered practically satisfactory.

The disadvantage of superheated steam is that special precautions are necessary on account of the high temperatures obtainable. In the case of a new plant the problem is not very serious, except that it may necessitate increased capital expenditure, but when superheated steam is applied to an old plant careful consideration must be given to various items. Superheaters are often installed on only one or two units in a battery of, say, six boilers in order to give a partial superheat, and in such a case no trouble need be experienced. The object of such an installation is to deliver steam to the apparatus at about the temperature of the saturated steam leaving the boiler; in other words, the gain in temperature balances the loss by radiation in the pipe system. An arrangement of this character is especially suitable where steam is used for process work such as boiling, its net effect being the same as if the boiler house were moved closer to the apparatus using the steam.

In the case of modern power stations using highly superheated steam for driving turbo-generators, it is necessary to install pipes and valves of special design, and constructed of metals which are capable of withstanding high pressure and retaining their mechanical properties when subjected to high temperature.[1]

There are many types of superheater, all of which have been designed for special purposes and to suit the positions they occupy on the steam-raising plant. The common practice is to incorporate the superheater with the boiler, either by fixing it inside, as is the case with water-tube boilers, or by placing it in close proximity, as with Lancashire boilers.

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[1] *Alloys Research Committee, Inst. Mech. Eng.*, p. 857, 1905.

Geared turbines are now frequently installed on board ship for the propelling machinery, and the dynamos, as well as other auxiliary machinery, are driven by direct coupled turbines. For battleships and fast ocean liners the turbine is now the recognized method of propulsion, and the result has been to introduce superheated steam on board ship. The superheaters used in this connection are similar to the locomotive type, consisting of a series of horizontal tubes expanded into a steel header generally placed vertically at the front of the boiler between the nests of smoke tubes. It is not usual to work the winches, pumps, and other reciprocating auxiliaries with superheated steam, and in order to avoid a double system of pipe lines a special steam distribution box is placed in the valve recess.

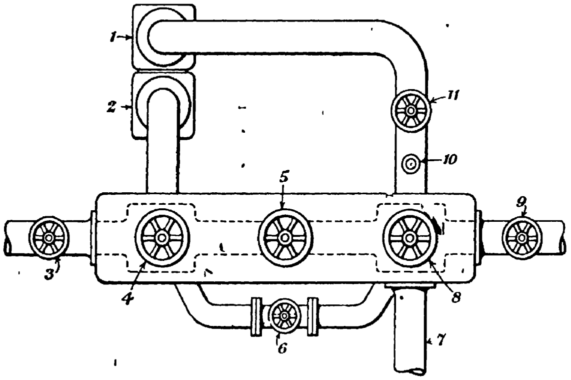

Fig 53.—Schmidt Superheated Steam Control Valve Chest.

1 Superheated Steam Header.
2 Boiler Steam Header
3 Auxiliary Boiler Steam Stop Valve
4 Main Stop Valve giving Steam either to Superheater or direct through Valve (5) to Engines.
5 - By-pass Valve.
6 Mixing Valve
7 Main Steam Pipe to Engines
8 Superheated Steam Stop Valve.
9 Auxiliary Superheated Steam Stop Valve.
10 Thermometer Pocket
11 Safety Valve.

Such an arrangement is shown in fig. 53, which represents a Schmidt valve chest. It will be seen that either superheated or saturated steam, or a mixture of both, may be supplied to either the main or the auxiliary range

The efficiency of a superheater falls rapidly if the tubes become coated with soot, and as it is impossible to clean the tubes when in position, " Diamond " soot blowers are fitted to most water-tube and marine boilers to blow any deposit off the tubes. The last-mentioned apparatus consists of a steam nozzle mounted on a framework in such a manner that it may be rotated, and thus efficiently clean a large area.

Cast-iron, gun-metal, and copper are quite unsuitable for superheated steam, and must not be used in the manufacture of any pipes, valves, or other apparatus which may at any time be subjected to high temperatures.

The correct operation of a superheater is an important matter which is surprisingly often neglected. Unless the performance of a superheater is kept under strict observation, the apparatus will soon become of little use as an auxiliary appliance for improving the general efficiency of a steam-producing plant. In power stations where the degree of superheat is carefully watched, because it has a direct influence on the generating capacity of the turbo-generator, the apparatus is usually well cared for, but in the case of factory boilers the superheater, once installed, is cleaned when the flues are cleaned, but otherwise left to look after itself. As already mentioned, superheater tubes become covered with soot which enormously reduces their efficiency, and in view of the fact that superheaters working in conjunction with Lancashire boilers can be inspected and that no special blowers are necessary, the frequent failure to maintain them at proper efficiency is very discreditable to all concerned.

In the case of water-tube boilers the arrangement of baffle tiles is of great importance. The makers go to a great deal of trouble, and pay considerable attention to the correct deflection of the products of combustion. In course of time baffle tiles become broken or large deposits of soot collect on the shelves, all of which affects the performance of the superheater. The results of neglect may often be serious, as the following example shows. In a water-tube boiler working at 180 pounds per square inch, the saturated steam temperature is 380° F., and in the case under notice the baffling arrangements, not being standard firebrick tiles, had become burnt. The leakage through the broken baffling sheets caused a short-circuiting of the gases which was not detected until the superheated steam temperature had reached 600° F., or 220° of superheat, when the engine using the steam gave trouble. The distribution of heat between the boiler and superheater was, of course, quite incorrect, and gave a low boiler efficiency.

Superheaters should be fitted with a thermometer, safety-valve, and drain cock, which last should be fitted with a pipe, preferably perfectly straight, either leading to the hot-well pipe system or simply terminating near the ground. Many accidents have been caused by thoughtless persons opening the superheater drain without first giving suitable warning.

The safety-valve is necessary because some types of superheater have to be flooded with water, when not in use, to prevent the apparatus being burnt out. This water can generally only be expelled by opening the drain, easing the saturated steam stop-valve, and blowing through the tubes. Some water will remain in the apparatus, and this must be gradually evaporated. Somebody may open the superheated steam valve too soon, thus causing water-hammer in the main steam range, in which case the safety-valve will lift.

It also frequently happens that, when a boiler with a superheater has not been working for some time, water collects in the tubes due to leaky stop-valves. When restarting a superheater such a contingency must always be provided for, whether it has happened or not.

Installing a superheater may save from 11 to 15 per cent. of the fuel used, especially with Lancashire boilers where the ratio of grate surface to heating surface is small. In some cases independently fired superheaters have been installed to meet special requirements, and fig. 54 shows such a piece of apparatus, made by Messrs. Babcock and Wilcox.

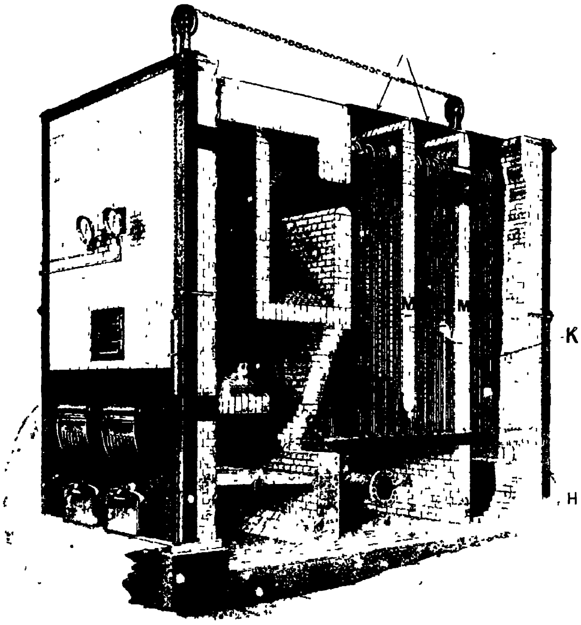

Fig. 54.—Babcock and Wilcox Independently Fired Superheater

A Main Connecting Pipe
G Tubes
H Collecting Pipe
K Damper
L Perforated Wall
M Brick Flame Baffles.
O Muffling Chamber.

The tubes of such a superheater should not be subjected to the direct impact of the furnace gases but should be in a chamber uniformly filled with gases, the combustion of which has been thoroughly completed, and which have a suitable temperature to ensure the degree of superheat required.

CHAPTER VI

ECONOMIZERS

(*a*) *High-Pressure Economizers.*—The economizer, as the name suggests, is an auxiliary appliance fitted to a steam-raising plant to increase the efficiency. It is used for heating the feed-water prior to entering the boilers.[1]

Economizers may be divided into two classes: high pressure and low pressure. A high-pressure economizer heats the water whilst it is under pressure; in other words, the pump delivers the water to the boilers through the economizer. The pressure is therefore slightly above that of the boilers, the difference being due to the resistance of the economizer.

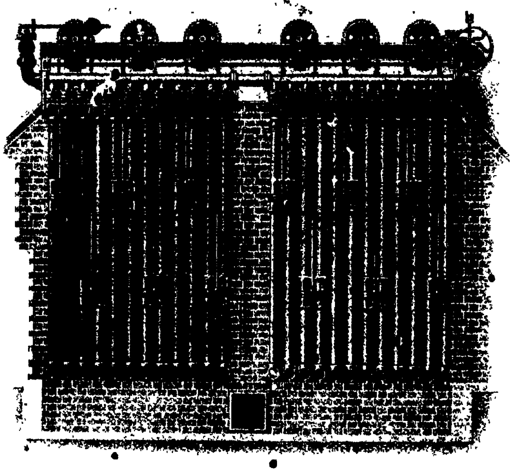

FIG. 55.—FRONT ELEVATION OF A GREEN FUEL ECONOMIZER.

There are several different types of each class, but the best-known high-pressure economizer is the " Green " type, named after E. Green and Son, Ltd., who are the patentees. This economizer, which consists of a number of tube elements placed next to one another, is illustrated in figs. 55 and 56.

The tubes are in standard lengths of 9 feet, are made of cast-iron, and have an outside diameter of $1\frac{9}{16}$ inches. They are shrunk by hydraulic pressure into cast-iron headers, and each element is an independent unit.

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[1] *Boilers, Economizers, and Superheaters*, R. H. Smith.

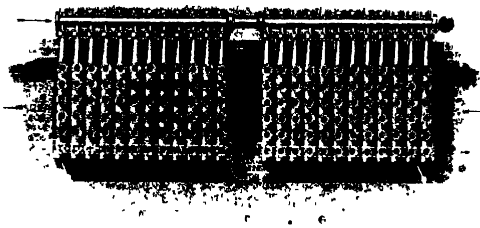

FIG 56.—PLAN OF A GREEN FUEL ECONOMIZER

Fig. 57 is a section through a header, and also shows the internal lid

The elements may be placed side by side to make an economizer of any size, and are connected by a special inspection header at the bottom, and another at the top.

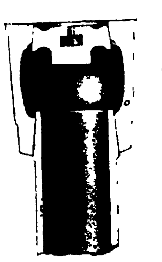

FIG 57.—INTERNAL LID FOR HIGH PRESSURES

The water enters the economizer at the bottom connecting pipe at the end at which the flue gases leave the economizer, and are therefore relatively cool. It passes out by the top connecting pipe where the gases enter the economizer, and are therefore hot The tubes are liable to become coated with soot, and in order to keep them clear special scraper gear is fitted, as shown in fig. 58.

Each tube is fitted with a scraper carried in a frame, one frame serving two adjacent elements or rows of tubes and being of the same width as the economizer. Two scraper frames are connected by means of a chain passing over a wheel supported on a special framework above the economizer. Each of the wheels is driven by a long shaft fitted with small worms, one opposite each wheel, and driven either by a small steam engine or by an electric motor. An ingenious device, fitted at the end of the frame carrying the driving gear, automatically reverses the rotation of the wheels when the scrapers have reached their upper or lower limit. The economizer is set in a special chamber which should be of ample size to permit inspection of the tubes, and so constructed that the soot may easily be removed from underneath the tubes. An inspection passage is required on one side of the economizer, and vertical wing-type dampers must be fitted at either end to prevent the gases circulating through the passage when the economizer is in use.

The gases generally pass straight through the economizer, but sometimes the units are arranged in two groups side by side, in which case the gases follow a horseshoe curve in passing through the complete installation. In water-tube boilers economizers are frequently placed very high above the ground, so that the gases on leaving the boiler pass straight through them. In such cases each boiler has its own economizer, but the usual practice with Lancashire boiler plants is to pass the gases from all the boilers through a single economizer, and this arrangement is the simplest because the economizer chamber merely becomes an elongation of the main flue. The position of the economizer varies a great deal according to the space available; but a by-pass flue should invariably be installed so that the boilers may be worked when the economizers are not in use.

Under no circumstances must the water enter the economizer at a lower temperature than 110° F., because when bituminous coals are burnt under conditions which do not permit of complete combustion, the tar will distil on the comparatively cool surface of the economizer tubes. The tar, together with the soot, will form a conglomeration with which the ordinary type of scraper cannot deal effectively. A special type of jaw scraper has been patented to overcome this difficulty, but the safest and best method of avoiding trouble is to raise the temperature of the inlet water to 110° F. This may be done in various ways, the most economical method being to use exhaust steam for the purpose. If no exhaust steam is available, a " National " patent circulator should be fitted, as illustrated in fig. 59.

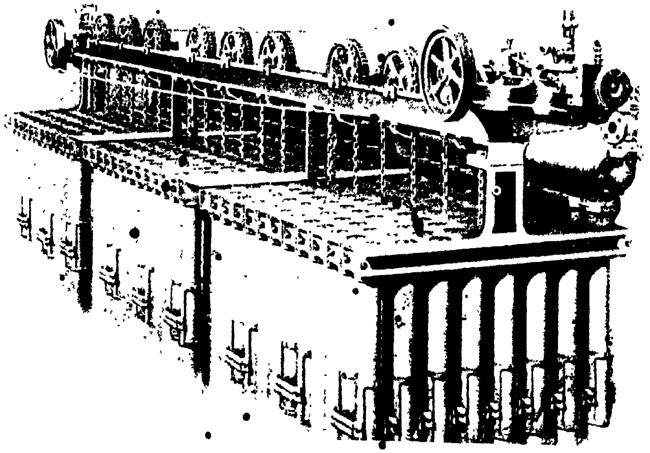

FIG. 58.—TOP VIEW OF THE GREEN FUEL ECONOMIZER, SHOWING SCRAPER ENGINE AND SCRAPER GEAR.

This apparatus works on the principle of an injector. A small branch pipe is taken from the discharge side of the economizer and connected to the circulator, which is placed near to the inlet header. The position of the circulator is shown in fig. 60.

The cold water enters the top of the circulator and passes through a nozzle in the body of the circulator. Round this nozzle is an annular space connected with the pipe from the outlet branch of the economizer. The action is, therefore, that the cold water draws with itself a certain amount of hot water, which may be regulated so that the temperature of the mixture will be not less than 110° F.

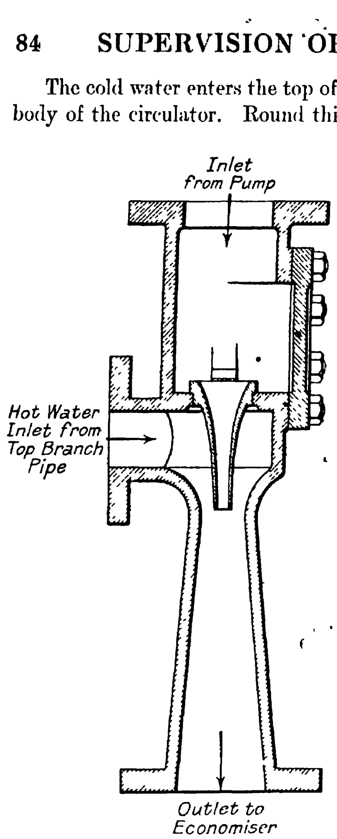

FIG. 59.—THE "NATIONAL" CIRCULATOR.

A mistake very commonly made by plant mechanics, especially in large power plants, is to suppose that a small economizer will discharge water at a high temperature because there is a large volume of flue gas available. If there is a large volume of flue gas available, there must be a correspondingly large number of boilers which produce this gas, and, as each of these boilers must be supplied with the necessary feed water, the volume that has to pass through the economizer will also be considerable. If a large amount of water is sent through a small economizer its velocity must be high, and as the increase in temperature is proportional to the time the water takes to pass through the economizer, the result obtained with a small economizer must be poor in comparison with what can be attained by installing the correct number of tubes.

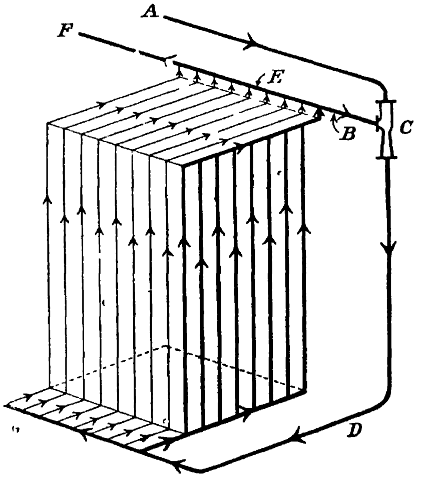

FIG 60.—DIAGRAM SHOWING ATTACHMENT OF "NATIONAL" CIRCULATOR TO ECONOMIZER

A Cold Feed Water Inlet.
B Hot Feed Water Inlet to "National" Circulator
C "National" Circulator.
D Inlet to Economizer
E Top Economizer Header.
F - Hot Feed Water Outlet

Fig. 61 shows the relationship between flue-gas temperature and heat transmitted per square foot of heating surface.

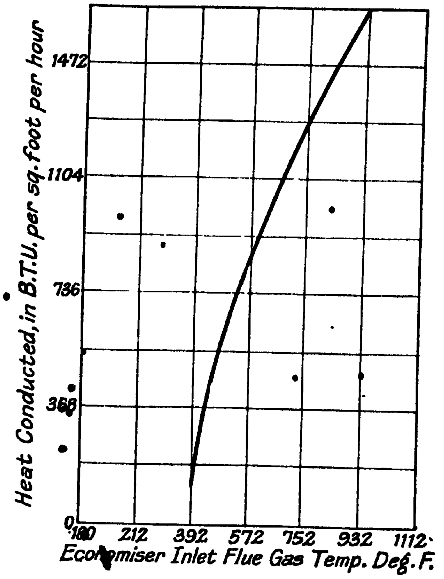

FIG. 61.—RELATIONSHIP BETWEEN FLUE GAS TEMPERATURE AND HEAT TRANSMISSION IN B.T.U. PER SQUARE FOOT PER HOUR FOR CAST-IRON ECONOMIZERS.

A new type of economizer has been introduced during recent years—generally in water-tube boilers, because these boilers are designed to meet the modern demand for increased steam pressures. The ordinary design of cast-iron economizer is considered not strong enough to withstand pressures which are mounting steadily year by year.[1] To meet the new requirements of high-pressure power plants Messrs. E. Green and Son have designed a tri-tube horizontal cast-iron economizer, and fig. 62 shows the new method of fitting the tubes into the header.

Each section consists of three tubes only, which, besides being forced into the header by hydraulic pressure, are secured by a patent "ringstay" joint.

Fig. 63 shows a Green's patent tri-tube horizontal economizer installed over a Babcock and Wilcox C.T.M. boiler. The water can be made to pass along the bottom row, returning along the next row and passing through each successive layer of tubes in series; or, on the other hand, it can be made to enter the lowest two or

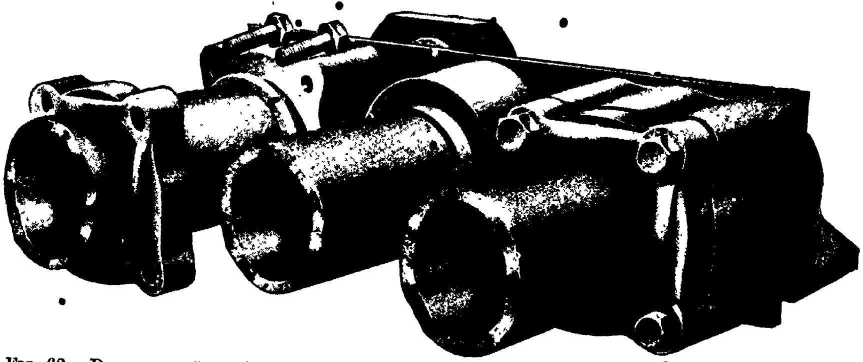

FIG. 62.—DETAIL OF GREEN'S TRI-TUBE HORIZONTAL ECONOMIZER HEADER SHOWING RINGSTAYS.

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[1] *Proc. Inst. Mech. Eng.*, p. 1597, 1910.

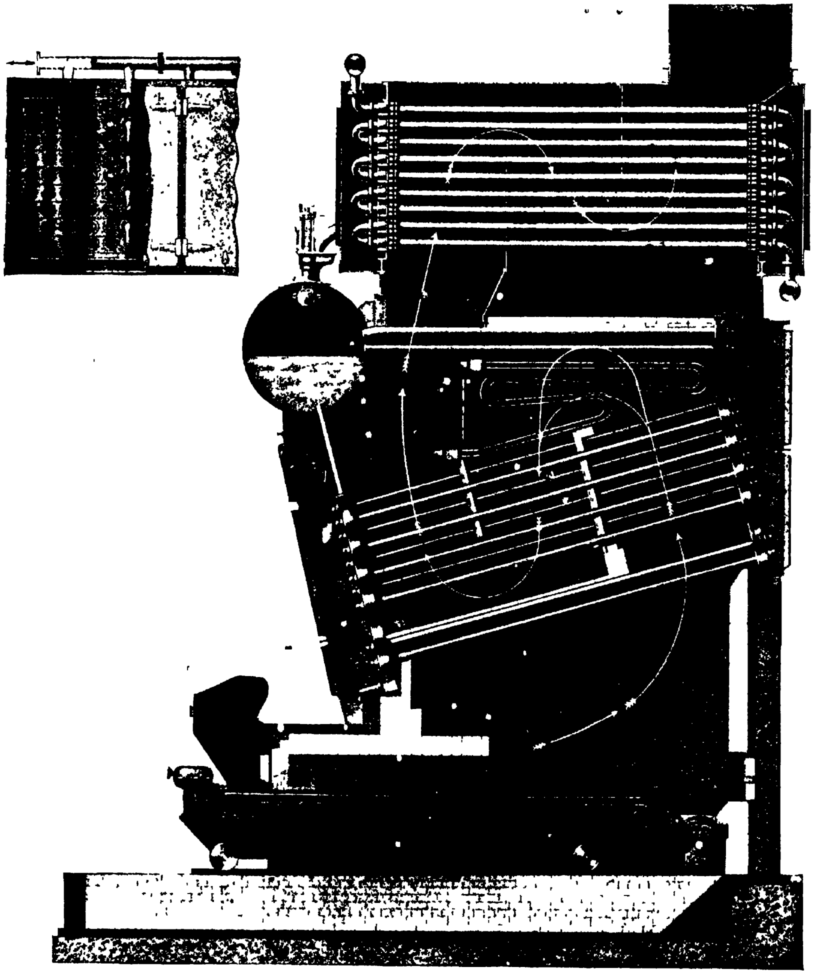

FIG. 63.—GREEN'S TRI-TUBE HORIZONTAL ECONOMIZER INSTALLED OVER A B. AND W. (C.T.M.) BOILER.

three rows simultaneously, returning along the next two or three in parallel, and back along the remaining rows, thus putting the economizer partly in series and partly in parallel as may be desired.

Steel-tube economizers are almost entirely confined to water-tube boilers, and because this type of boiler needs special care in the matter of feed water, the steel-tube economizers will probably not suffer to any great extent from impurity in the water, with the exception of a deposit of scale due to the " make-up " feed water, if the softening plant is not being worked correctly; and as such deposit is a result of bad management and is not the fault of the economizer, it is unfair to blame the apparatus for any trouble it may give on that account. The greatest mischief-maker is air, and it is in this respect that trouble will be experienced. Steel-tube economizers being a fairly recent invention, reliable information as regards their ability to withstand corrosion is very scarce. Any engineer who has had experience with boilers worked on the closed-feed system that is, in conjunction with condensers and an air pump, as are most power-station boilers and all boilers on board ship will know that he must constantly " chase air " if his boilers are not to suffer from corrosion.

Some very interesting experiments are being made on the Continent in connection with the lining of the top tubes of steel economizers. A very efficient system of coating the sides of steel boiling apparatus has been devised, and apparatus for this purpose has long been used in the chemical industry for pressures of 1,000 pounds and more.

Another important discovery, which may influence the use of steel economizers, is that which promises the power to galvanize efficiently by spraying, it being no longer necessary to immerse the article in a special bath. At present, however, the new method of galvanizing is only in its experimental stages. The ordinary system, although adopted by the Admiralty for galvanizing boiler tubes, is not corrosion proof. Chemical disintegration of the metal goes on under the galvanizing if the smallest flaw exists anywhere. With the new spraying system it is claimed that the liquid, owing to its very fine state of division, enters the grain of the steel under treatment.

The majority of water-tube boilers still send their gases through ordinary cast-iron economizers, because of the fear of the possible effects of corrosion should steel economizers be installed.

Economizers should always be above ground-level, so that they may not suffer from dampness, to which they are often subject when below ground-level or in the proximity of high ground. If the economizers are below ground-level the inlet, blow down, and other valves must be operated from the ground-level by means of extended spindles.

Cast-iron may become very brittle when stressed, as in pipes which are " sprung " into position, and any increase in temperature assists in bringing on fatigue of the metal. If an accident happens when a man is in the pit, there is little chance of his escape without a severe scalding, and any attention the economizer may require, such as the manipulation of valves, should be done from the surface.

(*b*) *Low-Pressure Economizers.*—Low-pressure economizers heat the water before it is delivered to the boilers, and work at atmospheric pressure. The temperature of the water is limited, because a pump supplied with very hot water is liable to hammer. If the economizer is placed some distance above the pump inlet, the pressure on the pump, due to static head, will permit of water being pumped at a higher temperature without risk of hammering, because the greater the pressure the higher the boiling-point, and hammering is caused by the presence of steam in the pump.

Low-pressure economizers are rarely found, but in exceptional cases, where it is impossible to increase the size of the high-pressure installation on account of lack of space, the flue gases are conducted through a special flue to a low-pressure economizer before entering the chimney. An economizer which has been condemned for further use under high pressure may be used as a low-pressure unit in which to subject the feed water to a preliminary heating before it is forced through the high-pressure economizer. The water is first pumped into a tank from which it falls by gravity through the economizer to the pump, the whole system being left open to the atmosphere. The gases, having already passed through the high-pressure economizer, are relatively cool, but trouble from corrosion is not eliminated, and such an arrangement can only be recommended where space does not allow of an extension to the high-pressure economizer and an old economizer can be procured.

A low-pressure economizer may also be a closed tank fitted with a pipe of moderate size, left open to the atmosphere, and heated by a small volume of waste gases from direct heated boiling pans, or any other source of waste heat which is not of sufficient importance to warrant the installation of special plant for its utilization. The engineer-chemist can make an economizer of this sort in the workshop, and, as in such cases the fuel used in generating the heat is charged to the factory account, any use that can be made of the waste gases for warming feed water will contribute towards raising the boiler department's efficiency without affecting the cost of operation. The quantity of heat wasted in exhaust steam is well known to be very large, but it is surprising to see how much can be reclaimed on some plants by utilizing the waste heat from sources which at first sight appear insignificant. Even if the feed water is raised only a few degrees before entering the economizer proper, a worth-while saving is effected.

CHAPTER VII

PUMPS, INJECTORS, AND METERS

(*a*) *Pumps.*—It has already been stated that the auxiliary appliances attached to the boiler house exhibit an even greater variety than the types and different combinations of the boilers themselves. No useful purpose would be achieved in a practical book by describing a small number of feed pumps and leaving out the majority of makes. Space permits only of reference to the different types of pump.

Pumps are of two types—namely, reciprocating and rotary. The former is, of course, by far the more common, and may be subdivided into such classes as vertical, horizontal, and radial. All pumps are described according to their design and arrangement, as, for instance, duplex vertical single acting, or single horizontal double acting.

Fig. 64 shows a pair of Weir direct-acting feed pumps with float tank and automatic steam-regulating gear. These pumps, although originally designed for use on board ship, are now extensively used on shore on account of their absolute reliability, high standard of workmanship, and sound design. It will be seen from the illustration that either pump may work with automatic steam regulation or with steam supplied direct; also, that each pump can supply independent feed ranges, and that each pump valve chest is fitted with a blind flange so that a second supply of water may be connected to the pump. It is very unlikely that two feed pumps, serving two independent ranges, and supplied with steam from two different pipe systems and drawing water from two sources, will fail to maintain the supply of feed water required by the boilers.

The rotary type of pump is represented by the various classes of centrifugal pump, whether turbine-driven, motor-driven, or belt-driven.

Fig. 65 shows a steam turbine-driven centrifugal boiler feed pump, made by Messrs. G. and J. Weir, which has been largely adopted for power-station use.

Fig. 66 shows an electrically driven centrifugal boiler feed pump made by Messrs. Mather and Platt.

The advantages of rotary pumps are that they form a small compact unit, provide a continuous easy flow without shock, and are inherently self-regulating in the matter of pressure at constant speed.[1] With rotary pumps it is impossible for an excessive pressure to be developed in the event of the check valves on the boilers being closed. Being automatic in their action, the pumps can be run continuously at one speed, and the attendant can do all that is necessary to regulate the feed water by operating the valve provided on each boiler. He need not be

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[1] *Proc. Inst. Mech. Eng.*, p. 361, 1917.

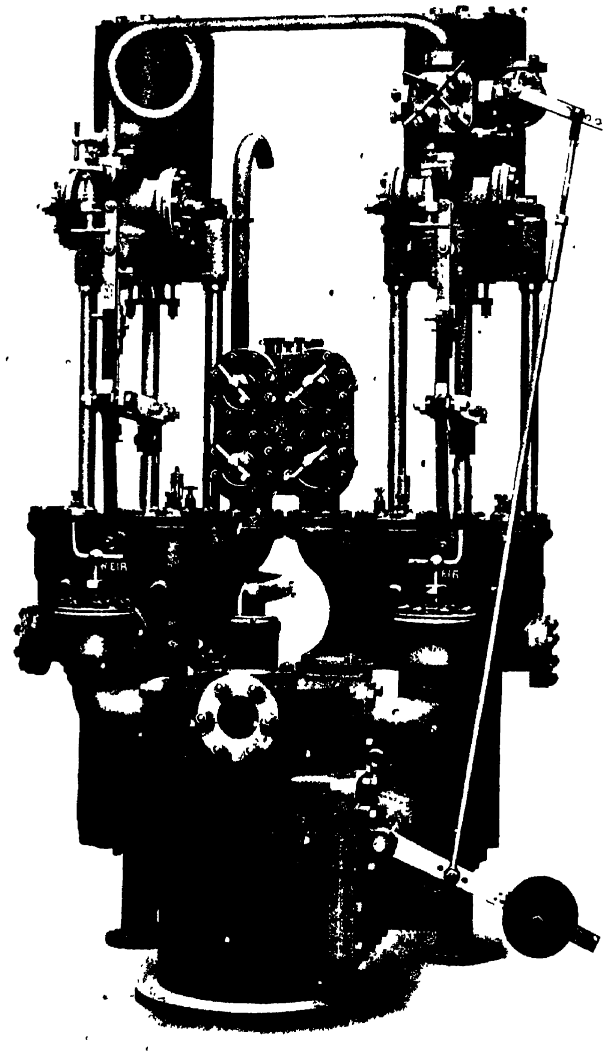

FIG 64.—A PAIR OF WEIR DIRECT ACTING BOILER FEED PUMPS WITH FLOAT TANK AND AUTOMATIC REGULATING GEAR

continuously running about between the pump house and the boilers for that purpose. The steam consumption of these pumps is from one-third to one-sixth that of a steam reciprocating pump doing the same work, and as no lubrication is required inside the pump, there is no possibility of oil being taken into the boilers along with the feed water. In existing installations where economizers are old and unfit to stand the full boiler pressure the two-pressure turbine feed pump can be very conveniently adopted. The first pump chamber receives the water direct from the hot-well, puts it through the economizer at 30 pounds pressure, or more if desired, and returns the water direct to the second pump chamber, whence the pump delivers straight to the boilers.

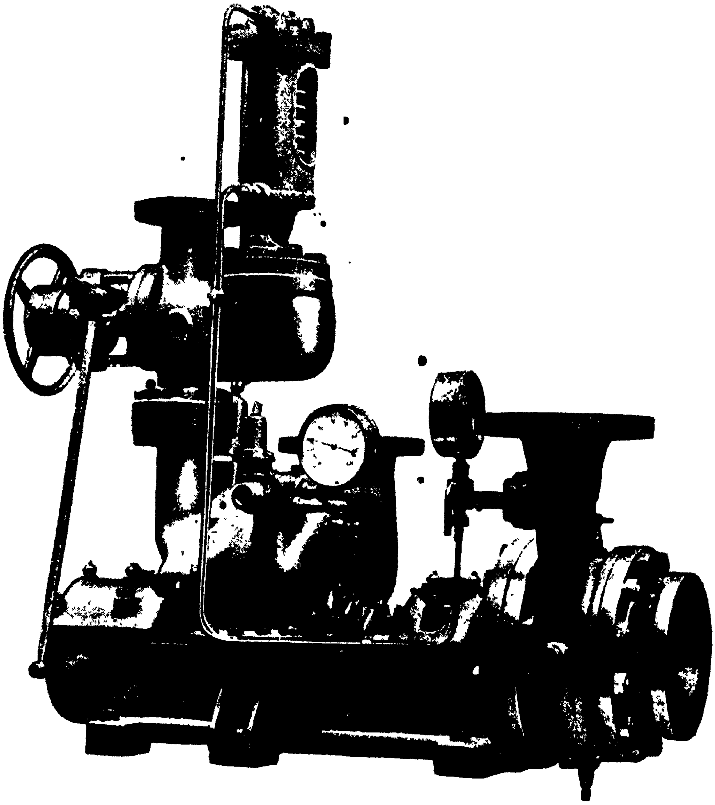

FIG. 65.—THE WEIR TURBO-FEED PUMP.

Such an installation is shown in fig. 67 with a Mather and Platt pump direct coupled to a steam turbine.

Regarding feed pumps in general, the important consideration is that the pumps shall be of sufficient size to deal with all the water when the boilers are working at maximum pressure. Pumping installations very often fall short of this requirement. In view of the vital necessity of a constant supply of water to the boilers, it is, indeed, positively astounding that those responsible for steam production should dare to take the risks that are run every day throughout the country. Pumps are too small; they are in a very bad state of repair; they can only be supplied with water from one source; two pumps are worked with the same steam pipe; there is but one feed pipe line—these are but a few of the dangerous conditions permitted. In many cases there are two, or even three, pumps on the premises, but only one is fit for use. The others are older pumps which, if thoroughly overhauled, would still serve as a stand-by.

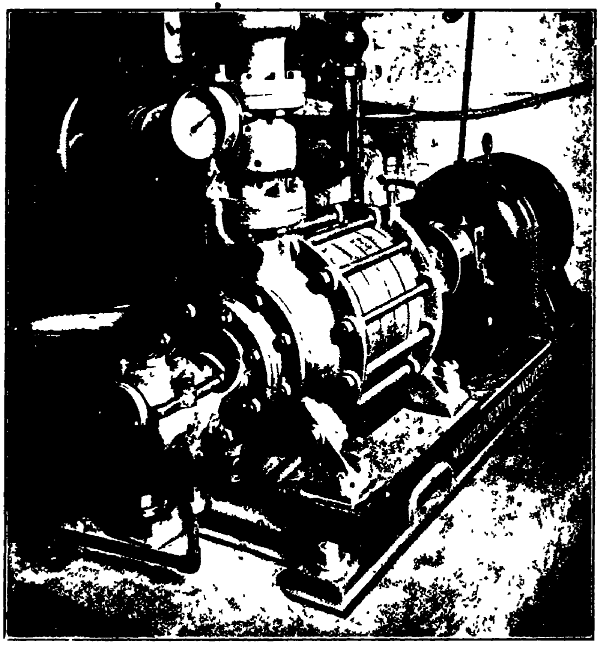

FIG. 66—MATHER AND PLATT ELECTRICALLY DRIVEN TURBINE BOILER FEED PUMP.

Pumps generally receive little or no attention, and it is a not uncommon experience to find a pump which is unable to supply the maximum quantity of water against the pressure at which the boilers are supposed to work. The size of the pump is sometimes at fault; but generally the trouble is due to sheer neglect. In most cases after the steam and water cylinders have been fitted with a new liner, a new set of rings provided for each piston, and the valve gear touched up a little, the pump —to use an engineer's expression—"simply looks at it." Such negligence is very frequent, though its cost in wasted steam almost staggers the imagination.

The more steam the engineer-chemist wastes on machinery in his department, the lower will be the general efficiency of his department. Economy in steam production usually means safety—a most important consideration in large cities where a boiler explosion may cause a heavy loss of life both directly in the boiler-room and indirectly by demolishing other structures.

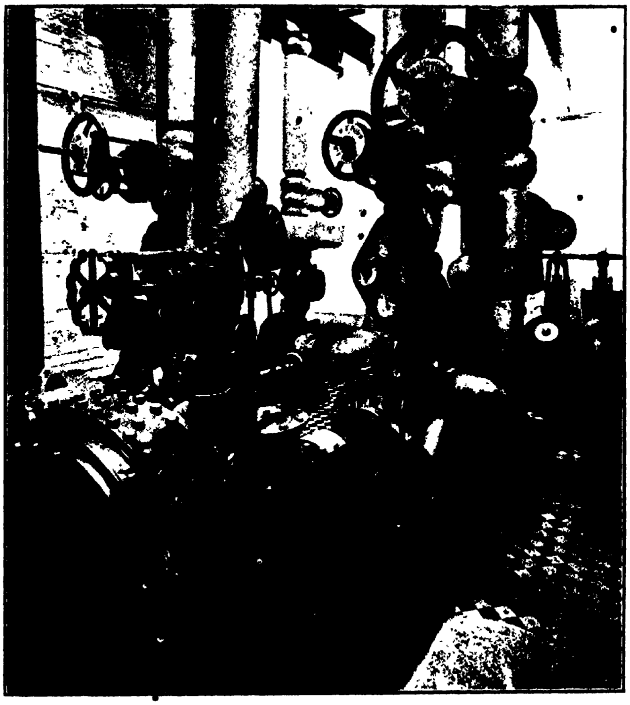

FIG. 67.—MATHER AND PLATT TURBINE-DRIVEN CENTRIFUGAL BOILER FEED PUMP WORKING ON THE TWO-PRESSURE SYSTEM FOR APPLYING LOW PRESSURE TO EXISTING ECONOMIZERS.

Fig. 68 shows the effect of such a boiler explosion on the surrounding buildings.

If two pumps are on one steam pipe and the supply fails, the fact that there are two pumps is not of much importance. If they are supplied with steam from two independent sources it makes all the difference. Where possible each pump should receive steam from two independent sources. Boiler houses in the basements of large buildings, such as stores, hotels, theatres, etc., in densely populated areas, should have separate electrically driven boiler feed pumps for emergency use.

A set of Mather and Platt's electrically-driven boiler feed pumps is shown in fig. 69.

Ordinary reciprocating pumps receive very little attention when working, and when such a pump commences to stick either at the top or bottom of the stroke, it is a common practice to shorten the stroke by screwing up the nuts regulating the travel of the steam valve. The result is that the pump only works a short stroke, the amount of water delivered is therefore less, and the steam and water cylinders become grooved over a corresponding length. The piston rod will also wear unevenly, so that when the valve gear is attended to, and the pump once more regulated to work at its normal stroke, the expected smooth working is not obtained. The piston, if fitted to suit the worn part of the cylinder, will be too tight for the extreme ends; or, if fitted for the ends, as is generally the case, it will pass water or steam, as the case may be, during the greater part of the stroke. When the stuffing boxes are repacked they will not be steam-tight, because when the grooved part of the rod is in the gland and the nuts are tightened, the end of the rod will be tight, and the pump will stick. If tightened when the end of the rod is in the gland, the packing will be too loose for the smaller part of the rod. Such inefficiency is only one of the evil results of shortening the stroke of a pump, instead of attending to the valve gear in the first instance.

FIG. 68.—RESULTS OF A BOILER EXPLOSION.

(*b*) *Injectors.*—Injectors are generally fitted to small boilers and locomotives. They should not be used as the only means of supplying water for large boilers, but as a stand-by they are unrivalled, by reason of their cheapness, convenience, and small size. If there is no second feed pump or other emergency apparatus, an injector is a necessity. Whatever may happen to the feed pump an injector offers an inexpensive solution of the problem of keeping the plant in operation when the normal feed supply fails. Another advantage of the injector is that although the normal supply has failed, the water introduced into the boiler will still be hot.

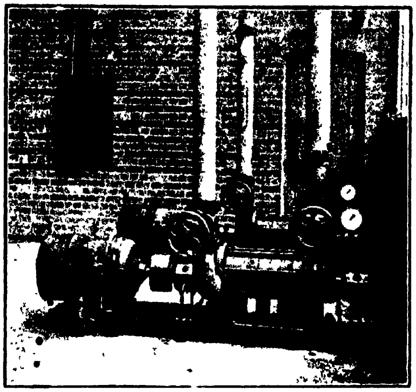

Fig. 69.—Mather and Platt Electric Motor-driven Turbine Boiler Feed Pump.

There are several types of injectors, automatic and non-automatic, which may be divided into adjustable and non-adjustable. Automatic, or self-starting injectors start immediately the steam and water are turned on, and regulate themselves if the supply is for any reason interrupted.

Figs. 70 and 71 illustrate the Gresham patent self-acting restarting injector.

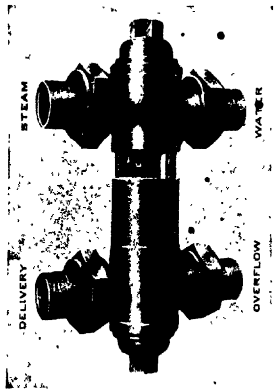

Fig. 70.—The Gresham Self-acting Restarting Injector.

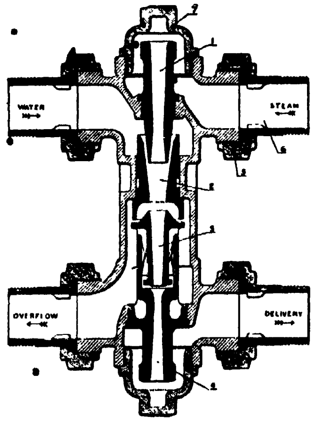

Fig. 71.—Sectional Elevation of the Gresham Injector.

Non-automatic injectors are very simple in construction, but require attention when they are working, unless the steam and water supplies are not subject to variation. Although injectors can draw water—the height depending on the temperature of the water and the discharge pressure—the less the lift the better. Non-automatic injectors are more suitable when the feed water has to be lifted. In compound injectors the requirements of a high lift and ability to deliver against a high pressure have been combined. The apparatus consists of two injectors in one casting, the first delivering the water to the second. One is designed for lifting the water, and the other is constructed for forcing. When used as an emergency set, an injector may draw from a tank supplied with water from the street main, the height being regulated by a ball valve arrangement in the tank.

Fig. 72 shows the Gresham injector adapted for such emergency use.

(c) *Water Meters.*—In order to ascertain correctly the performance of a boiler, it is necessary to measure the raw materials consumed, or, in other words, exact

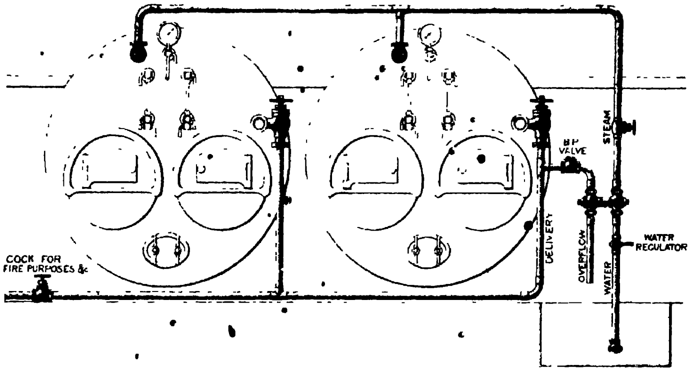

Fig. 72. Arrangement of Self-acting Injector when Fitted to a Lancashire Boiler

weight of water and coal supplied.[1] The third factor, air consumption, need not be measured, because air costs nothing. This need only be checked to avoid supplying it in greater quantity than can efficiently be used.

There are two methods—which may be termed the "pressure" and the "no-pressure" systems—of ascertaining the amount of water supplied to a boiler plant. In the former the water passes through a meter placed on the discharge side of the pump between the pump and the economizer (or the boiler, if there is no economizer), and is measured at boiler pressure. In the latter the water falls by gravity from a special tank to the inlet branch of the pump, and the rate of flow through the tank is recorded by instruments or actual weighing.

An example of an instrument for recording the amount of water used is the Lea recorder. This instrument works in conjunction with a tank which is divided into

[1] *Testing Boilers, Engines, and Auxiliary Appliances*, W. F. Pullen.

three compartments, the outlet of the second compartment being fitted with a special plate which has a V-notch attached. The water enters the first compartment, which serves to steady the flow to the second chamber, and before it can enter the second chamber it has to pass through an arrangement of baffle plates. From the second chamber it flows over the V-notch to the third compartment, and thence to the pump. The dimensions of the V-notch fitted are known, and the flow of water at a given head can be ascertained.

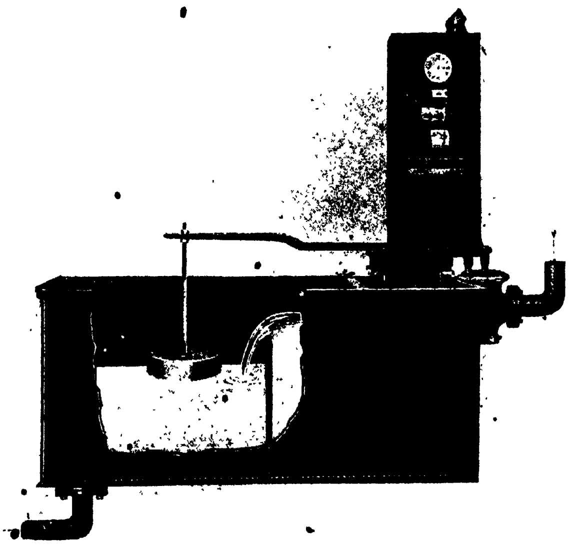

FIG. 73.—ARRANGEMENT OF THE LEA RECORDER FOR MEASURING BOILER FEED WATER.

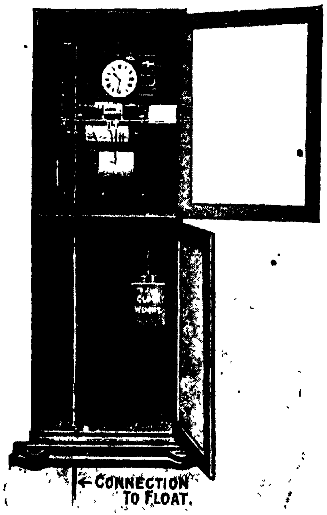

FIG. 74.—INDICATING, RECORDING, AND INTEGRATING MECHANISM OF THE LEA RECORDER.

Fig. 73 shows a Lea recorder and measuring tank. The discharge through the V-notch is proportional to the head of water, and, in order to record the amount automatically, a float with a long vertical spindle is fitted to the second chamber. This spindle engages the recording mechanism, which moves a pen over a chart rotated by a clockwork drum.

Fig. 74 illustrates the recording mechanism which transposes the vertical movement of the float spindle into a horizontal displacement of the recording pen. The advantage of this type of recorder is that, no matter what the temperature of the water may be, the actual amount is measured in pounds per hour, and the area under the curve shown will represent the total weight of water for the period under consideration.

In pressure meters the volume only is recorded, and a correction must be made when converting the volume into weight, because the density of water decreases as the temperature rises. Fig. 75 shows the weight of a gallon of water at different temperatures. The water in forcing its way through a pressure meter moves certain mechanism which operates the indicating gear.

There are various types of pressure meters. Some are reciprocating, and others have a rotary motion An example of the reciprocating type is shown in fig. 76, which represents the apparatus made by Messrs. Glenfield and Kennedy.

The water in passing through the meter moves the piston and, therefore, the rack (23) up and down. This is effected in the following manner. The rack (23) engages with the pinion (21) which is keyed to the shaft (45). The lifter (20) is also pinned on to

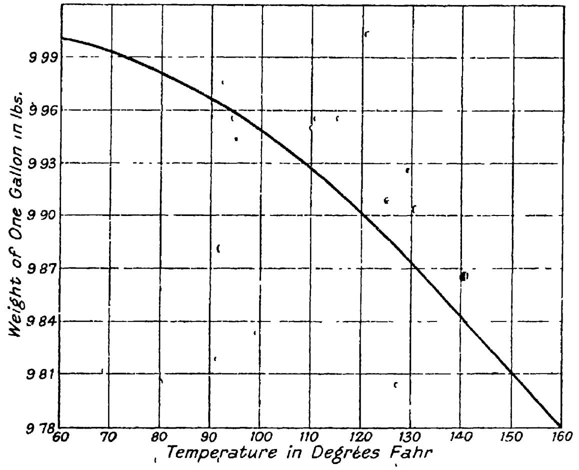

Fig. 75.—Weight of a Gallon of Water at Different Temperatures.

the shaft (45), and therefore engages the weighted lever (35) during the major part of every up-stroke, either on the right or left hand side of the buffer box. When the weighted lever has been carried up a certain height, it overbalances and, striking the bevel wheel with arms (25), rapidly turns the cock through the required angle to change the direction of flow through the meter. The meter is shown in the position of having nearly completed its upward stroke. The shaft (45) engages two bevel wheels, each of which alternately drives the counter-mechanism, and the volume of water is indicated on a series of clocks similar to that fitted to an ordinary gas meter. The two bevel wheels, driven by the shaft (45), are similar to the free wheel of a bicycle, one rotating the clockwork, when the rack turns the shaft (45), in a clockwise direction, and the other when the motion is counterclockwise. There must, therefore, be no leaks in the discharge system, for in that case the rack would be liable to work up and down over a very short stroke every time the pump succeeded in forcing any water through, say, a faulty valve, and as the recording mechanism indicates every movement of the rack, the clock may advance, although there is very little water passing through the meter.

This type of meter is very reliable, and is very suitable for measuring the water consumed by the boilers, because the meter can be read at any time, and it is not necessary to compute any result from a chart. The amount is measured in gallons.

An example of the rotary type of meter is that made by Messrs. George Kent, and shown in fig. 77.

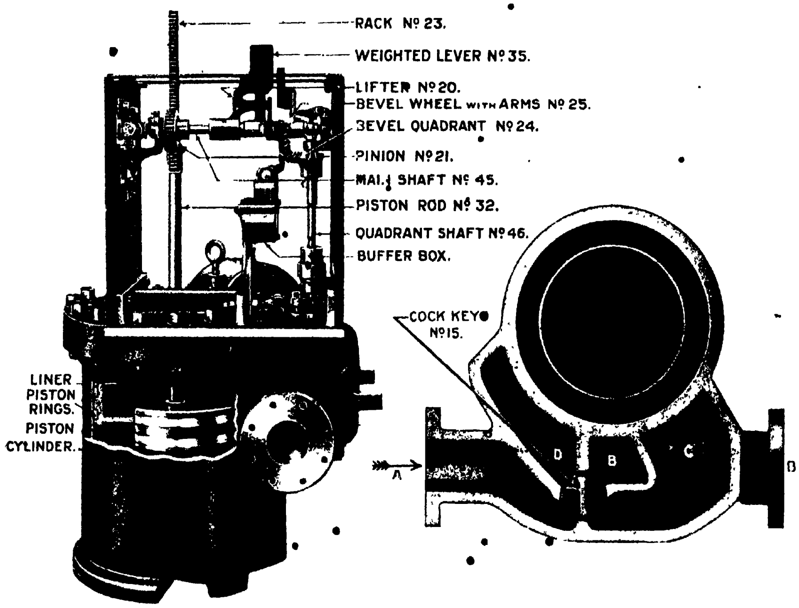

FIG. 76.—SECTION THROUGH A GLENFIELD AND KENNEDY HOT WATER METER.

In this case the water, in passing through the meter, moves in one direction a central displacer which is so balanced that a sudden shock or increase in pressure does not affect the accuracy of the meter. The over-all dimensions of the meter A, D and the height C are all small, which makes the instrument particularly suitable for mounting on the top of a Lancashire boiler when making an individual test such as an experimental evaporation test with a small sample of special fuel.

Whenever great accuracy is required, as when testing a boiler for guaranteed performance, it is advisable to measure the feed water by actually weighing it. The usual method of doing this is to use two tanks of equal size, standing next to one another on two weighing machines, so arranged that both tanks discharge into one large tank.

Such an arrangement is shown in fig. 78. The small tanks should be fitted with overflow pipes, since they are of necessity placed near and above the large tank and, in the event of one of them being permitted to overflow through negligence, it is important to prevent the waste water from running into the large tank and thus spoiling the test. The tanks may be filled by means of two-way cocks fitted with two short lengths of pipe, or two separate cocks may be used. Each tank is filled until the arm on the weighbridge tilts, when the cock is immediately turned off and the supply diverted into the other tank. By this means the tanks may be filled alternately, and the same weight of water be added to the large tank every time. Before commencing a test the level of water in the large tank must be

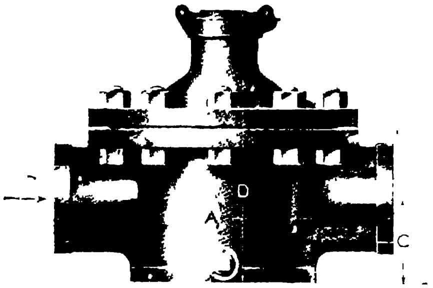

FIG. 77 - THE KENT UNIFORM METER FOR HOT WATER

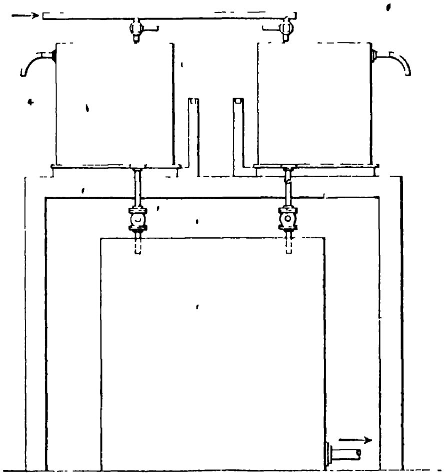

FIG 78 — DIAGRAM SHOWING METHOD OF WEIGHING FEED WATER WHEN USING TANKS

accurately measured in order to allow for any difference in level at the end of the test. This method of measuring the feed water is only necessary for special occasions, as, for instance, when testing a new boiler.

All meters should be regularly calibrated to ascertain their accuracy from time to time (see Chapter XIV.).

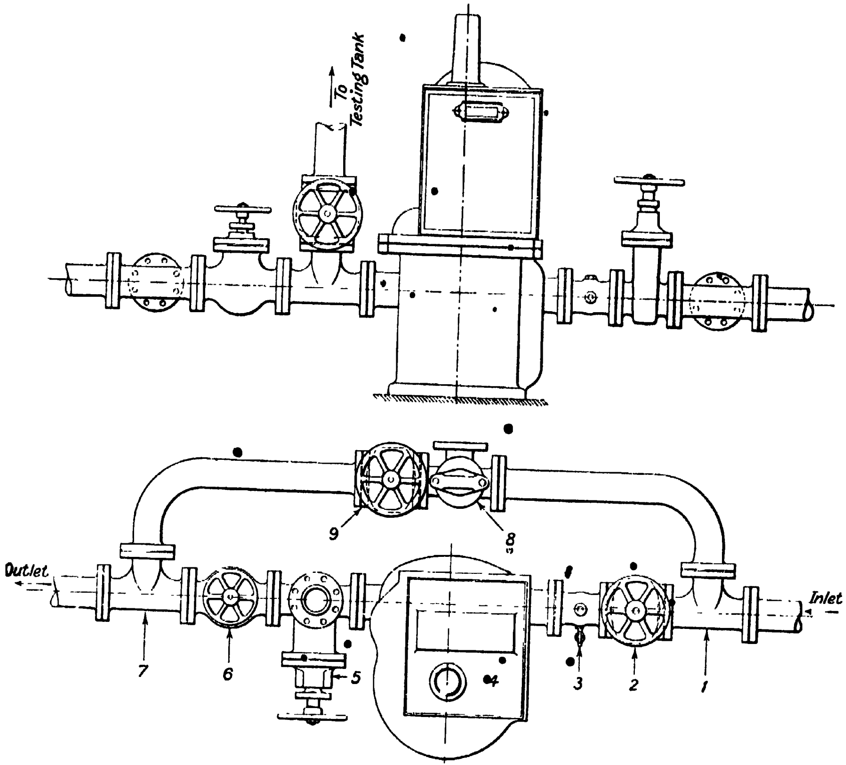

FIG. 79.—ARRANGEMENT OF A PRESSURE TYPE BOILER FEED WATER METER.

1 Water Inlet.
2—Screw-down Valve.
3—Sample Casting with Thermometer Pocket.
4—Water Meter.
5 Screw down Valve.
6 Non-return (Check) Valve.
7—Water Outlet.
8—Safety Valve.
9 By-pass Screw-down Valve.

Some plants are fitted with an injector only, and where this is the regular method of feeding the boilers the water meter must be in the inlet (suction) side of the injector. Otherwise the meter will record the water plus the condensed steam.

Fig. 79 shows the method of connecting a water meter, and it will be noted that a screw-down valve is on the inlet side, whilst a screw-down non-return valve is on the outlet side of the meter.

SECTION III.—CARE OF SUBSIDIARY PLANT

CHAPTER VIII

HANDLING OF FUEL

(*a*) *Storage.*—It has already been said that the water evaporated and the fuel burnt must be recorded day by day with the greatest accuracy compatible with everyday working conditions. No works manager will allow accurate daily records to be taken if this means stopping the plant for even a short period.

The water presents no difficulty The meter is read off at the same time every day; and, if great accuracy is required, the level in the gauge glass is measured, but this is a refinement only needed when carrying out a special test.

The accurate measurement of the coal presents a more difficult operation, and varies to a great extent with the nature of the plant. Very few firms, other than power stations, trouble to keep detailed records in this respect. The fuel may arrive by road, rail, or water, and the character of the conveyance in which it is transported must determine the system of weighing

Fuel is commonly delivered by road, and the vehicle conveying it must pass over a weighbridge and be weighed on arrival at the works. Modern machines are fitted with a patent stamping arrangement, so that when the lever has been adjusted a special card is inserted in the stamping box, and on this is imprinted, by depressing a lever, the exact gross weight. When the vehicle has been emptied it must be reweighed, and the same card used for the record stamping. Subtraction gives the net weight of the fuel. The advantage of this method is that all the cards are dropped into a special box and, no matter how many other vehicles, bringing raw materials or taking away manufactured articles, may pass over the weighbridge, there is no confusion such as often occurs when the weights are recorded in a book. Care must be taken that the weight of the empty vehicle is recorded every time. Many firms do not cart their own fuel, and different carts are often used by the same contractor. Even though the same driver may be regularly employed bringing the fuel, he may not drive the same cart on every occasion, and the weight of the usual cart may have been increased by repairs. Such changes are very common, and cases are on record in which errors due to negligence in the matter of weighing have remained undetected for two or three months.

Special attention is required in the case of steam-driven road wagons, which are often employed to bring fuel from the railway station to the works. All these are fitted with feed water tanks of considerable capacity, which are generally filled at the works. If proper record is not made of the weight of water in the tanks, to say nothing of the coal supplies carried by the wagons for their own use, serious errors may arise. In some cases the weight of the so-called empty wagon is recorded at the same figure, whether the feed water tank is full or empty, and although on the average the errors each way over a year may balance and give an approximately correct result, such practices are not scientific recording.

Even with a small boiler plant a vehicle may make eight journeys a day, so that a mistake of a few pounds each trip will soon cause serious miscalculations of fuel burnt, and, if the efficiency of the boiler plant is high, quite ridiculous percentages may be obtained by working upon incorrect figures so far as fuel consumption is concerned. The process of weighing the full cart, reweighing when empty, and dropping the stamped ticket in a box sounds simple, but some men are capable of astonishing vagaries when required to record the weight of fuel passing into a works.

A complication may arise when, owing to a stoppage of the normal source of supply on account of industrial trouble, fuel has to be taken from the reserve supply. The necessity for weighing this fuel before it is burnt in the boiler house, notwithstanding that it has previously been weighed for the purpose of checking the fuel merchant's account, is more than most men seem able to understand.

Quite a number of firms weigh the fuel delivered to their works, but many accept the weight on the delivery note handed in by the driver. Those who do weigh the fuel generally get as far as sending the figures up to the office, where they are entered in a book and presented as monthly returns. This, of course, means little as far as the boiler department is concerned, and can only be used as a basis for rough calculations. It may be possible to compute some such figures as tons of paper per ton of coal, or barrels of beer per ton of coal, but as such figures rarely take into account energy supplied from outside sources in the form of electricity or gas, they are not even an indication of the power plant efficiency. The firms which accept the driver's check as being correct generally use the weights only for checking the monthly account.

Although the weights are of little use in working out the boiler-house consumption, which requires scientific exactitude, it is always safer to reweigh the vehicle as described. In some cases where the coal is fetched direct from the colliery in tip carts the contractor is paid so much a ton for carting, and drivers have been known to stop on the way and water the coals. Fine slack can absorb a considerable quantity of water without showing signs of having been "treated." In any case, a little water every time is all that is necessary; otherwise the difference between the weight of the coal delivered and the weight paid for becomes too noticeable at the end of a month.

The same weighing system should be employed with fuel transported by rail. The trucks should be passed over a weighbridge when full, and again when empty, because the weight painted on the side of the truck is not always correct. Trucks are often repaired and not re-registered by the railway company. The engineer-chemist should watch to see that the trucks are really emptied, because the men are very careless about this work and, although a few small lumps here and there, with

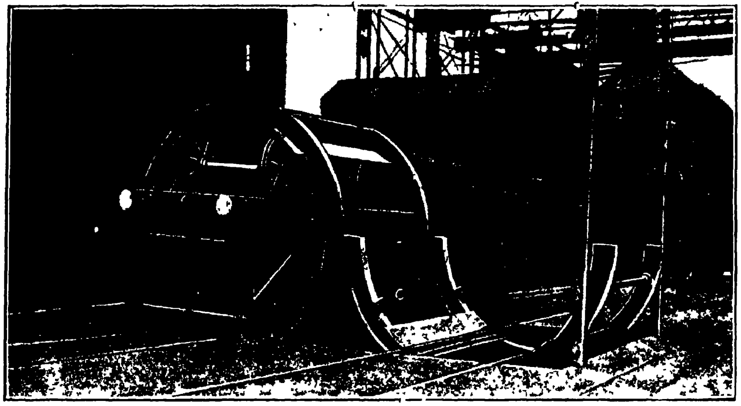

Fig. 80.—The Bennis Rotary Truck Tippler

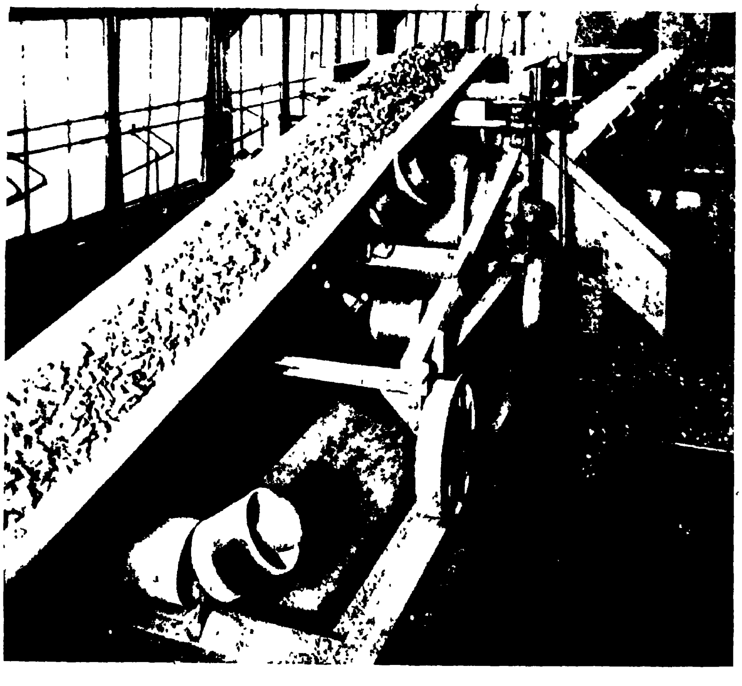

Fig. 81.—Mitchell Belt Conveyer filling Overhead Bunkers.

a little dust may be all that remains, the waste may easily amount to 30 pounds per truck. In a large boiler plant using eight trucks per day, the loss in a month will at this rate be about 3 tons. Many boiler plants are provided with automatic truck unloaders to obviate the possibility of waste from this cause.

Fuel may also arrive in barges or other floating craft from which it may be loaded into trucks which are weighed by running them over a weighbridge, or it may be taken ashore by grabs or transported by mechanical link conveyer. When either of the two last-mentioned methods is adopted the fuel can be measured by passing it over a continuous weighing machine. The layout and shape of the bunkers will influence the method of keeping records.

When large quantities of fuel arrive by rail and they cannot be dealt with on a weighbridge for fear of causing congestion, they will probably be tipped into a pit and transported straight to the overhead bunkers by means of a bucket conveyer.

Fig. 80 shows a Bennis patent truck unloader which discharges the fuel into a pit from which it is raised by means of a conveyer to the bunkers. The bucket transporter generally feeds a belt conveyer which runs along the top of the bunkers and discharges the coals wherever required.

Fig. 81 illustrates a belt conveyer erected by Messrs. Mitchell Conveyer and Transporter Co., Ltd., filling overhead bunkers. The belt passes over rollers mounted on a movable trolley, and so discharges the fuel before commencing the return journey. A continuous weighing machine may be installed in connection with the belt conveyer, and fig. 82 shows a Blake-Denison automatic and continuous weigher working under such conditions.

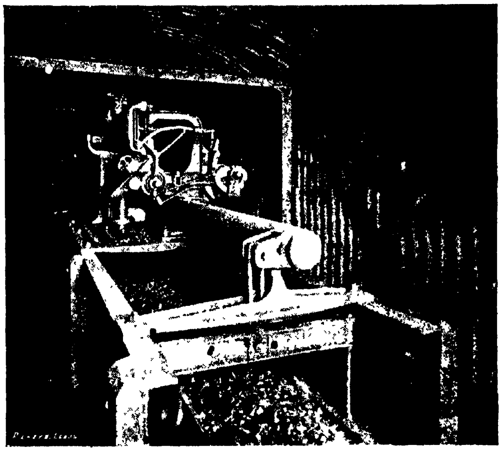
FIG. 82.—A BLAKE-DENISON CONTINUOUS WEIGHER APPLIED TO A BAND CONVEYER.

The principle is that of suspending a short section of the conveyer and of weighing the material as it passes over without stopping. If the section is 10 feet long the machine will weigh and record, with a maximum error of one half of 1 per cent. the weight of the material every time the conveyer travels 10 feet. The weighing machine is driven by the returning conveyer belt itself, so that it is not deranged by any variations in speed. If the fuel arrives by barge and is unloaded by a crane and automatic grab, the weigher is incorporated above the machinery operating the crane.

Fig. 83 illustrates a Blake-Denison automatic weigher working in conjunction with a grab.

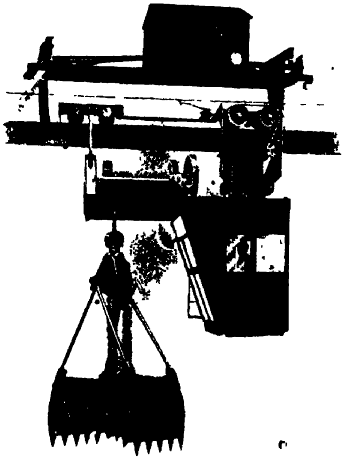

FIG. 83.—THE BLAKE-DENISON AUTOMATIC TELPHER WEIGHER APPLIED TO AERIAL TRANSPORT INSTALLATION.

So far only the weight of the fuel delivered has been considered, and in the majority of industrial boiler plants there is little difference between this weight and that of the coal actually burnt, although this statement by no means implies that the delivered weight may properly be used for calculating the weight burnt. In plants where the fuel is tipped on to the floor, guesswork is the only method of estimating the quantity burnt during week-ends when the fires are banked. For this reason floor storage is not a proper method for keeping fuel. Very many industrial boiler plants are arranged with a row of brick bunkers running parallel with the front of the boilers. Such bunkers should be erected wherever they have not already been provided. All the fuel delivered into these bunkers should be weighed, and twice a week—once will suffice in very small plants—the fuel in the bunkers can be levelled. This operation takes but a few minutes. By means of a board, marked in feet and inches, the level of the fuel from a fixed point, say the top of the bunker, may easily be measured.

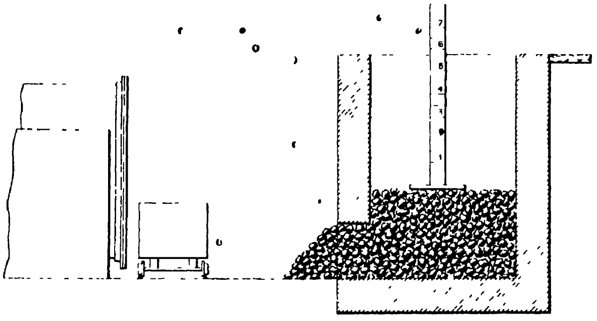

FIG. 84.—SECTION THROUGH ORDINARY BRICK BUNKER, SHOWING METHOD OF MEASURING AFTER LEVELLING OFF THE FUEL.

This method of measuring is illustrated in fig. 84. If the bunkers are square in section, or where the four walls are vertical, a simple calculation gives the fuel in the bunkers.

$$\left.\begin{array}{r}\text{Fuel in hand at last record}+\text{fuel added}\\ -\text{fuel now in hand}\end{array}\right\}=\text{fuel burnt.}$$

In power stations where the bunkers are of large dimensions to hold a good supply of fuel against emergency, the only correct practice is to weigh the fuel after it has left the bunkers, and one way of doing this is to use an automatic tipping machine which is provided with a counter. This counter may be read at any time, and, provided that the stoker hopper and shoots are kept always full, the exact amount of fuel burnt is the difference between the counter-readings. An alternative method where water-tube boilers are installed is to measure the fuel as it passes on to the grate of chain grate stokers. The fuel in this type of mechanical stoker passes under a door which regulates the thickness of the fire to be carried. The fuel burnt in any given time is therefore the content of a solid block having for its dimensions the width of the grate, the thickness of the layer of fuel, and the distance the grate has travelled. Since equal volumes of coal—or, at any rate, of the coal generally burnt with mechanical stokers—have the same weight irrespective of the size of the pieces, the thickness of the layer of coal is directly proportional to the weight of the coal passing under the regulating door.

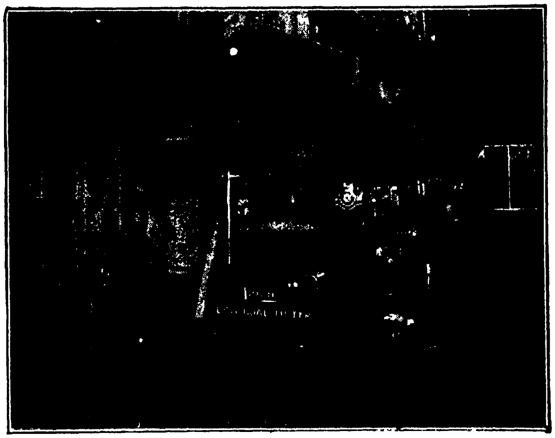

FIG. 85.—A LEA COAL METER FITTED TO A CHAIN GRATE MECHANICAL STOKER.

The Lea coal meter illustrated in fig. 85 makes use of the above fact, and is an instrument for registering the fuel passing under the grate. The recording mechanism is operated by the stoker driving shaft and regulated by the height of the door under which the fuel passes.

The arrangement is shown diagramatically in fig. 86, from which it will be seen that the important part is a spirally toothed drum, which is driven by the chain grate stoker mechanism and which in turn drives the counting dials. The spirals on the drum are of different lengths, and the number which engage with the clock-work driving wheel depends on the lateral position of the drum, which is in turn dependent on the position of the fire door. When the door is fully open, the clock-work will be driven by that part of the drum on which the spiral teeth go right round the circumference of the drum, and a continuous recording will take place If the door is partly open the drum is in such a position that the teeth only engage during part of the revolution, and the counter-clockwork is driven accordingly.

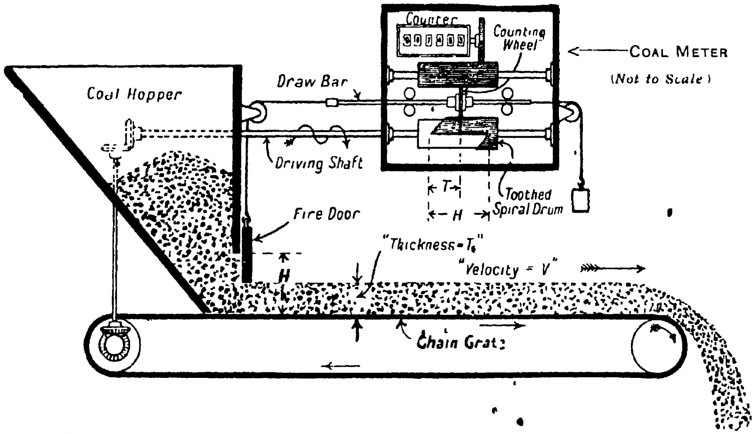

FIG. 86.—DIAGRAM SHOWING THE PRINCIPLE OF OPERATION OF THE LEA COAL METER

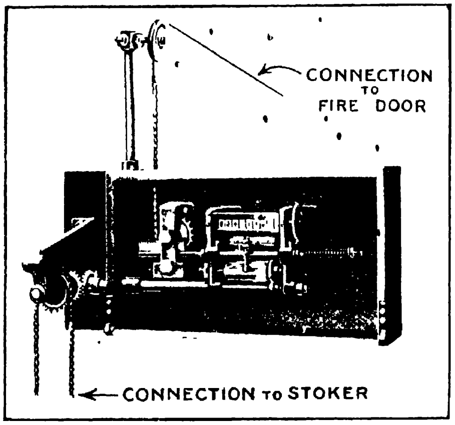

FIG. 87.—INSIDE VIEW OF A LEA COAL METER

Fig. 87 shows the mechanism of a Lea patent coal meter

The greatest difficulty the engineer-chemist has to contend with is the mixing of different fuels. In large power stations the fuel is tipped into the bunkers as it arrives, irrespective of whether it be North Country, Midland, or Welsh coal. The barge or railway wagon must be emptied, otherwise there will be demurrage to pay. As there is generally little space for storing any large quantity of fuel—and, in any case, such storage means handling the fuel twice, which is expensive—the bunkers have to be filled at once. The only method of keeping different fuels apart under such circumstances is to divide the overhead bunkers into sections, each boiler having its own section. If the space be large enough, a further division parallel to the front of the boiler is advisable, with the shoots arranged to take coal from the front or rear section. With such an arrangement one batch of fuel may be finished before another is started, and, particularly if the fuels vary considerably, more economical results can thus be obtained. In some cases the division is almost a necessity.

Coke is becoming more and more popular as an ideal fuel from the point of view of economy. Its advantages are that the air supply required for its perfect combustion can be accurately regulated, and that it does not produce smoke. The last-mentioned characteristic, of course, means that there is no waste due to unburnt volatile matter, since coke burns with a very short flame, and the heat is transferred to the boiler by radiation. To overcome the disadvantage of the short flame the Sandwich system of burning a mixture of coal and coke has been introduced, and when worked in the correct proportions this gives excellent results. The coke and coal are fed into separate compartments in the stoker hopper, as shown in fig. 88, and form the bottom and top layers of the fuel as supplied to the grate.

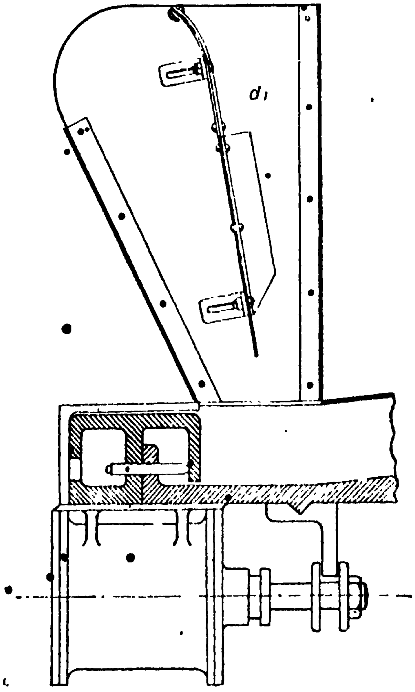

FIG. 88—THE "SANDWICH" SYSTEM OF FEEDING COKE AND COAL TO AN UNDERFEED STOKER.

In order to adjust the proportion of coke and coal correctly the fuels should be stored in separate bunkers. Another great advantage of the Sandwich method of burning is that excellent results are obtainable by mixing very low-grade fuels, which, under ordinary conditions, cannot be efficiently consumed, with a small percentage of coke.

(*b*) *Transport.*—The method of transporting the fuel inside the works depends entirely on the layout of the plant.

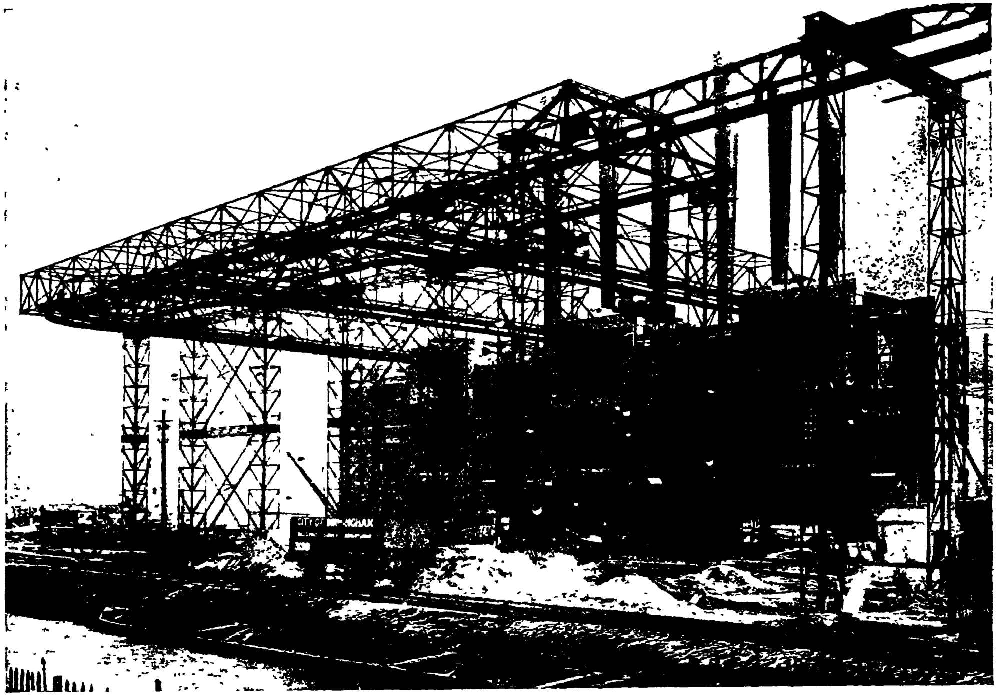

FIG. 89.—GENERAL VIEW OF COAL HANDLING TELPHER PLANT AT NECHELLS POWER STATION.

Fig. 89 illustrates the plant erected by Messrs. Mitchell Conveyer and Transporter Co., Ltd., at the new Nechells power station. This may be taken as an example of a modern fuel handling telpher plant of the type required by large power stations. The fuel arrives by rail or barge, and is handled by five telpher carriages, each with a capacity of 50 tons per hour, which deliver the fuel to the bunkers or store. Each grab lifts 1½ tons, and is operated from the telpher car which runs over the whole system of track, all points being electrically controlled from the driver's cabin.

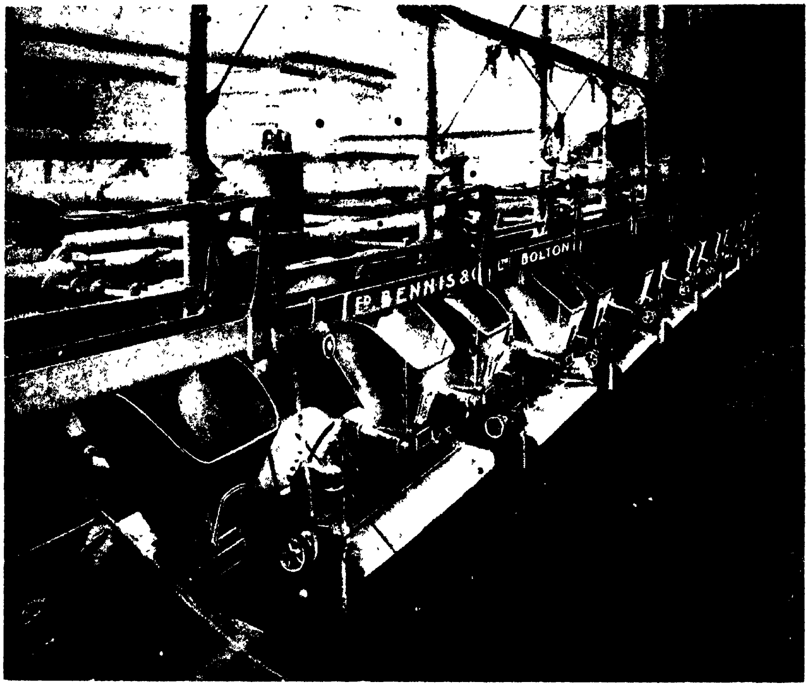

FIG. 90.—LANCASHIRE BOILER PLANT FITTED WITH A BENNIS LINK CHAIN CONVEYER.

In quite a few boiler plants the fuel arrives in a vehicle and is tipped on to the floor in front of the boilers. If mechanical stokers are fitted, each boiler may have a small endless chain elevator, fitted with buckets, which fills the hoppers in front of the boilers.

In collieries the boilers often burn the residue from the coal-washing machines, and in these circumstances some type of steel link conveyer is used, because the wet fuel is best propelled whilst lying in a steel trough. Such an arrangement is shown in fig. 90, which illustrates a Bennis steel link conveyer.

The boiler plants of works or institutions in a city are often below the ground or street level, in which case the vehicle is tipped in the street, and the fuel falls down special shoots to the bunkers, which are on the same level as the firing floor. If the fuel arrives by rail it is often shovelled out of the wagon straight into the bunkers, which may be level with the ground or below the rail level

On account of the high wages prevailing to-day, labour-saving devices are installed wherever possible, and fig 91 shows a Bennis patent truck unloader.

Where there are overhead bunkers the wagons discharge into a pit, a bucket conveyer raises the fuel to the level of the top of the bunkers, and a belt conveyer carries the fuel along the top of the bunkers

Fig 92 illustrates a Bennis bucket elevator raising fuel from a tippler pit to the overhead bunkers.

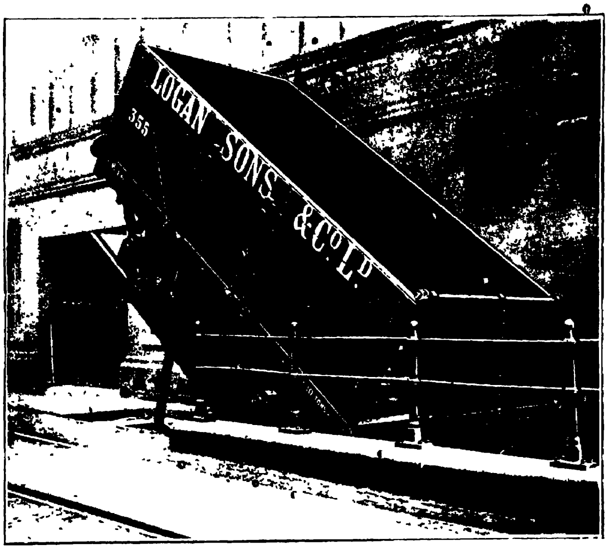

Fig 91 The Bennis End Truck Tipper

The design of fuel handling plant constitutes a special problem beyond the province of the engineer-chemist, who has to work the machinery placed at his disposal, and not to design some new scheme. Small alterations to existing plant, however, often help matters considerably, and an ordinary belt conveyer, with small steel buckets attached, can easily be made in the workshop. Such a conveyer can often be installed over existing shafting, such as stoker driving shaft, and can perform small duties which will save a man's wages, besides causing less dust than hand shovelling.

Descriptions of fuel-handling apparatus have only been given for the purpose of illustrating the importance to the engineer-chemist of seeing that fuel is properly weighed at the right stage. Coal falling by gravity from overhead bunkers is the neatest arrangement—and that now universally adopted in modern power stations.

(*c*) *Treatment.*—It should not be necessary to treat the fuel except in very special cases. Coal, for instance, can be obtained in all sizes from lumps to fine dust, and those firms which buy large hard coal will probably find it just as cheap to buy washed nuts and save the cost of labour in breaking the large coal. Breweries may be mentioned as examples of manufacturing plants which at present often burn the very best large coal obtainable.

Some fuels, such as brown coals, containing a large percentage of water, can with advantage first be dried. The method generally adopted is to utilize the flue gases, which are passed for the purpose through a spacious flue divided in the middle by steel sheets. The gases pass through the lower portion, and the brown coal is transported by a conveyer through the top portion, the wet fuel entering at the end where the flue gases leave.

The most important case in which treatment is required is that of pulverized fuel installations. Burning of coal in pulverized form is now the practice in some of the largest power houses in America—for example, at Lakeside, Milwaukee, River Rouge, Detroit, and the new Cakokia station which, when completed, is to supply St. Louis.[1] The great advantage of this method of burning is that the fuel is in the most intimate relation with almost exactly the quantity of air theoretically necessary for perfect combustion, and the highest possible temperature can therefore be attained.

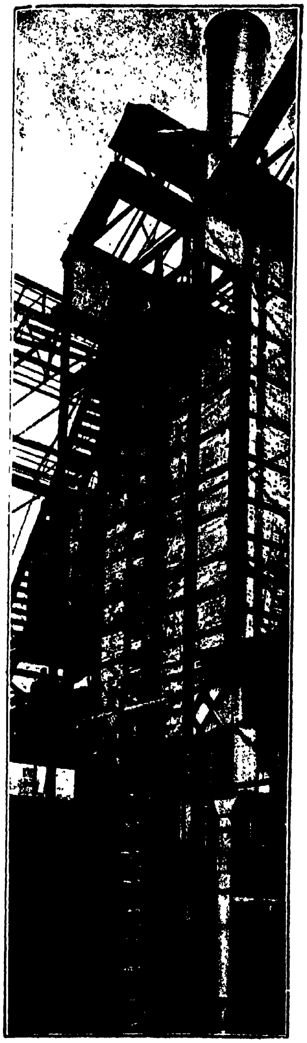

FIG. 92.—THE BENNIS GRAVITY BUCKET CONVEYER ARRANGED TO FEED BUNKERS ON THE INWARD JOURNEY AND TO TAKE AWAY ASHES ON THE RETURN JOURNEY.

The systems for burning pulverized coal may be divided into two distinct groups, viz., the unit system, in which the fuel is pulverized at the furnace with a separate pulverizer for each furnace, and the multiple system, in which the coal is pulverized at a centre and transported as a powder to any number of furnaces. A typical installation for the burning of powdered fuel includes arrangements for breaking, drying, and pulverizing the coal, transporting it to the furnace, and feeding it through the burner.

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[1] *American Fuels*, Bacon and Hamor.

In Great Britain the cement industry makes considerable use of this method of generating heat, but with this exception, installations of this character are as yet rare in this country. A specialized literature is growing up around the subject, and the needs of the reader who wishes to investigate the possibilities of pulverized fuel can only be met by a study of the latest works devoted exclusively to the problems of this department of science.

CHAPTER IX

HANDLING OF ASHES

(*a*) *Removal.*—We have seen that the engineer-chemist's interest in the handling of fuel arises out of his responsibility for the machinery provided for that purpose, and his obligations to see that the boilers always have a plentiful supply of fuel and that records are kept of the exact weights of fuel consumed. His interest in the handling of ashes is very similar in character. Firstly, he is responsible for the removal of all boiler-house refuse, whether by hand or mechanical means. Secondly, he must so arrange matters that the removal at no time interferes with the efficient working of the boiler plant. Thirdly, he must know the exact weight of the whole of the fuel which is not consumed.

The majority of industrial boilers are of the Lancashire type, which has a comparatively small grate surface and is fired in most cases by hand. Water-tube boilers, which have a very large grate, are fired by mechanical stokers and, as a direct outcome of the design of the stoker, are self-cleaning.

Even supposing mechanical stokers did not remove the clinker automatically, some other method than hand cleaning would have to be introduced into large modern power stations. Water-tube boilers burning coal and fired by hand were very common in ships of the Royal Navy before oil fuel was adopted, and the experience gained with such grates, generally provided with four fire doors, showed that even with highly skilled naval ratings the cleaning of a grate took two stokers twenty minutes, or ten minutes for each quarter of the grate. Hand cleaning thus produced the same result as if one of the fire doors had been open for forty minutes, and during that time had allowed cold air to rush into the combustion chamber. Among the advantages of mechanical stoking, therefore, must be reckoned the fact that no fire doors need be opened to clean the grate.

With hand-fired furnaces there is one efficient method of cleaning fires which is recognized as the correct method both on shore and afloat. When it is desired to clean a furnace the fire is allowed to burn down fairly low. A rake is then taken, and all the good fuel which is still burning is pushed over to the right side of the grate. The clinker on the left side is now pulled out of the furnace, so that this side is absolutely clean and no ashes or incombustible matter remain. The good coal, which is still burning, is then pushed over on to the left side from the right side. At this point a little green fuel should be thrown on to the left side and the furnace door shut. The fireman can rest for a minute whilst the green fuel ignites, so that the furnace is not altogether out of action. The clinker from the right part of the grate is now raked out, and when this side is clean all the burning fuel from the left side is spread equally over the grate.

The method is simple enough, yet very few firemen ashore work to this plan. The general rule on shore is to push the burning fuel right back to the firebridge and to rake all the clinker out together. After this the burning coal, which is not very much, is raked over the grate, and a mass of fresh green fuel is thrown on. The steam pressure will drop much more quickly when the job is performed in this manner, as the furnace is doing very little good all the time the cleaning is going on. With the other method half the furnace only is out of commission at a time.

The method first described may also be worked by cleaning half the grate in one furnace, then doing half that of another furnace, and returning to finish the cleaning of the first. The rotation in which furnaces are cleaned should be as shown in fig. 93.

In any case, two firemen should not clean fires in the same boiler at the same time, doing one furnace each, in order to "get it over" as quickly as possible. Many firemen work in pairs when cleaning out fires, and the result is that, both furnace doors being open, a large volume of cold air rushes into the flues and a whole boiler at a time is *hors de combat*. Also the work progresses at such a speed that those boilers which are finished do not have time to make good the loss in pressure while others are being dealt with. The steam pressure, therefore, gradually falls until all the boiler fires have been cleaned, after which it slowly creeps back to normal. This is the very worst thing that can happen, because all the machinery in the factory slows down, and the attendant immediately regulates the stop-valve to give the engine more steam, which the boilers cannot supply. The results are painful. In many cases a special halt of a quarter of an hour is called to give the boilers a chance to pick up pressure, which is quite unnecessary if the cleaning out is undertaken according to proper routine.

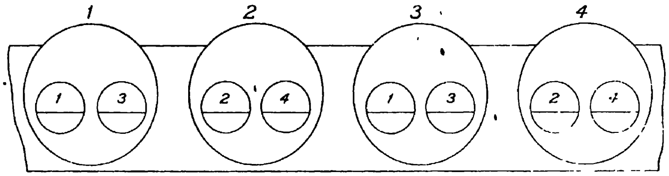

Fig. 93.—Diagram showing Rotation for Cleaning out Furnaces of a Lancashire Boiler Plant

Although it is imperative that the engineer-chemist should eliminate from his plant such inefficiencies as those just described, he may need to exercise considerable tact to secure observance of his wishes. Firemen, especially at sea, are easily annoyed, and if irritating methods are adopted when introducing science into the "firehole," the consequences may be injurious alike to the efficiency of the boilers and to the engineer-chemist or his deputy.

Apparatus has, however, been perfected which will at least mitigate the effects of inefficiency in cleaning fires.

Fig. 94 shows a patent firebridge fitted to a Lancashire boiler grate, and indicates how, when the live fuel is pushed to the back of the grate, the inrush of cold air is partially checked.

All coals contain a certain percentage of incombustible matter which, when melted by the heat of the fire, produces slag.[1] The molten slag runs into cakes, and if the firebars are old and worn at the top, as shown in fig. 95, it will trickle down the sides and fill up the air-space between the bars.

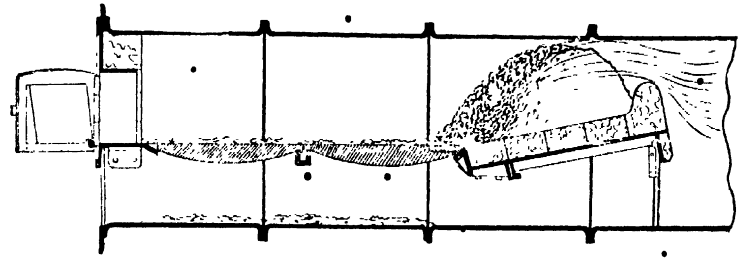

FIG. 94.—FURNACE EQUIPPED WITH APPARATUS TENDING TO IMPROVE EFFICIENCY AND TO REDUCE LABOUR OF CLEANING FIRES.

A grate covered with slabs of clinker can be cleaned with a rake, but when the molten slag has run between the firebars a slice must be used in order to lift as much away as possible. When a rake only is used the top layer may be torn away, but the slag will remain wedged between the firebars, choking up the air-space.

It also very often happens that firemen simply pull everything out of the furnace, regardless whether it is good fuel still alight or dead clinker. They then fetch a few shovelfuls of burning coal from the next boiler and add a large quantity of green fuel. By employing this method they cause the steam pressure to drop rapidly. The fires will take some considerable time before burning brightly, during which period the pressure continues to drop.

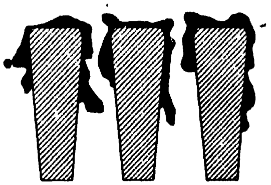

FIG. 95.—SLAG ON FIREBARS BLOCKING UP THE AIR SPACE.

Another cause of trouble in connection with cleaning fires is that most firemen give themselves far too much work. For instance, they rake all the ashes on to the floor and then shovel them into a barrow. This is a waste of time, and is certainly not conducive to cleanliness, the importance of which in a " firehole " cannot be too strongly emphasized. When fires are cleaned, the ashes should be raked straight into a barrow placed ready in position by the ash wheeler. The ash wheeler should spray water on to the ashes, as they are drawn from the furnace, and thereby prevent dust from flying about. A water service pipe running along the wall of the boiler house or attached to the front of the boilers, with suitable connections for a flexible hose, will be found very useful. The engineer-chemist should have a light steel plate made which can readily be fixed to the front of the boiler, shaped to rest on the barrow. This portable plate, illustrated in fig 96, will prevent half the ashes falling on the floor, to cause more work and dust in sweeping the floor clean

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[1] *Technical Paper*, No. 306, Washington.

It also serves the very important function of preventing the front of the boiler suffering from cold water which invariably splashes against it when the ashes are damped and combines with the hot clinker to form corrosive fumes

The engineer-chemist should remember that dust is less objectionable during the short time it flies about than when it settles round feed-valve spindles, on the boiler tops and round all the mountings, causing a general appearance of dirt Moreover, this boiler-house dust is as hard as carborundum, and whenever a valve on which dust has settled and worked into the stuffing box is manipulated, a grinding effect is produced The result is that the spindles become worn, dirt finds its way into the gland packing, and leaks manifest themselves.

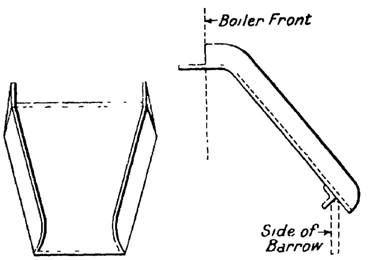

FIG 96.—ASH PLATE FOR USE WHEN CLEANING FIRES

When everything is covered with dust, a mechanic will not think of going round the plant to tighten up leaky glands, etc, firstly, because he probably will not see they are leaking, and secondly, because the proposition is too unattractive When these leaks commence they moisten the dust and as this retains the moisture, corrosion commences at once. Very bad accidents have been caused by a weakening due to corrosion taking place unseen Lack of cleanliness is one of the causes responsible for this dangerous condition. If everything is kept reasonably clean, the eye will detect any faults very much more quickly.

The surroundings in which a man works influence his character, and therefore the quality of his work Hence it is most important to let a man work in surroundings which are as congenial as possible, always remembering that paint and polish do not add anything to efficiency. It is not in human nature that a fireman should take an interest in his work and the plant under his care when the boiler house is so dirty that he cannot attempt to move the smallest thing without becoming smothered in ashes and soot. If the plant is fairly tidy, the fireman will do his share to keep it so, but when he sees things going to ruin he naturally does not concern himself.

Another thing to be borne in mind is that the "firehole" is looked upon as a dirty place, because coal, which, in popular fancy, is also dirty, is burnt there. Considering the price of the raw material and the very neat appearance of some of the little factories in which steam is made, surely it is worth while to give the boiler house at least the same attention that the remainder of the factory receives. If the boiler house were kept cleaner, it would probably be included in the manager's

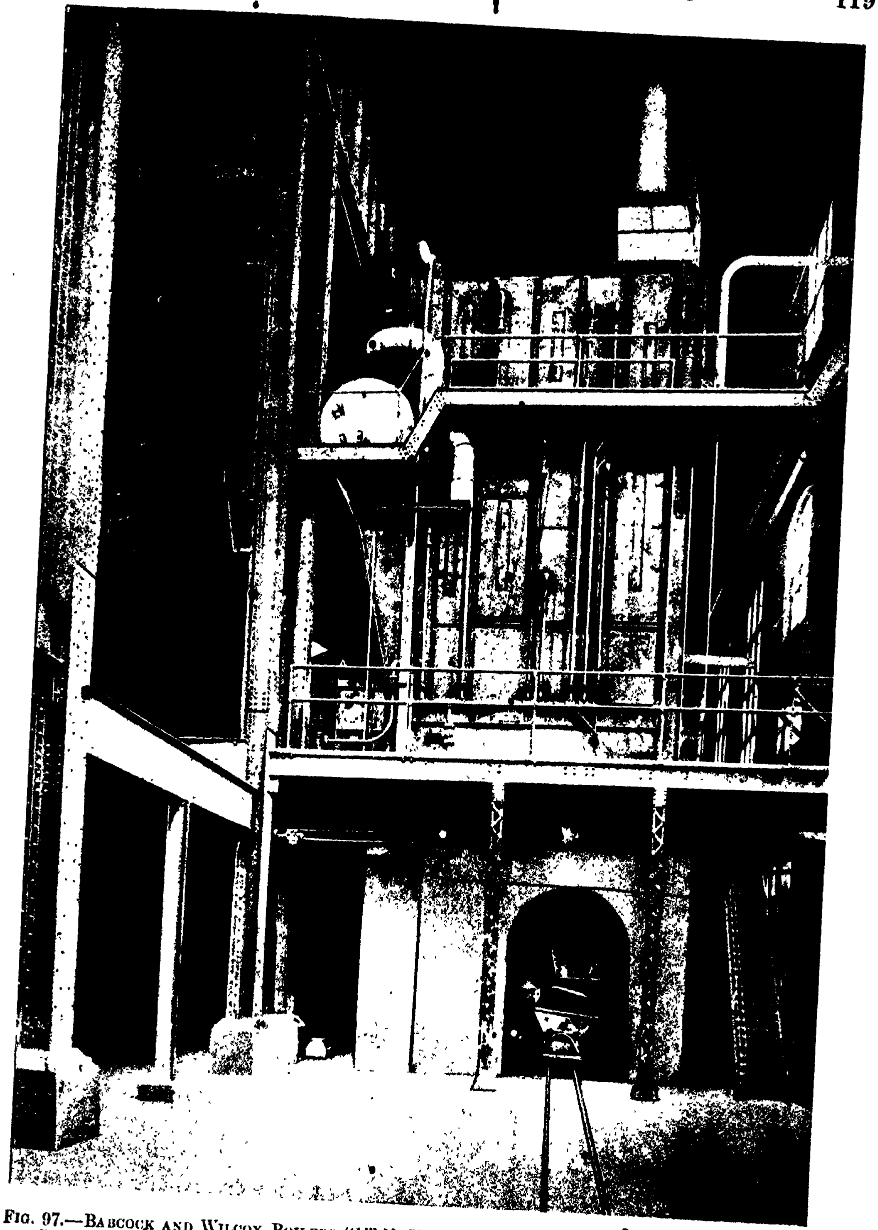

FIG. 97.—BABCOCK AND WILCOX BOILERS (C.T.M. TYPE) FITTED WITH SUPERHEATERS, CHAIN GRATE STOKERS, AND SUPERIMPOSED ECONOMIZERS, WITH DIAMOND SOOT CLEANERS ON BOILER SIDES. VIEW SHOWING ASH TUNNEL.

round of inspection, and he would interest himself in this section in the same manner as in the rest of the plant under his control

With mechanically fired boilers the question of cleanliness practically resolves itself into the removal of the boiler refuse. Water-tube boilers, for instance, are generally arranged in such a manner that the refuse, when pushed over the back of the stoker, falls into specially constructed hoppers These hoppers are fitted either with sliding doors or hinged doors opened by worm wheel attachments Small trucks on rails let into the floor are run under the hopper discharges and the removal of the refuse presents no difficulty

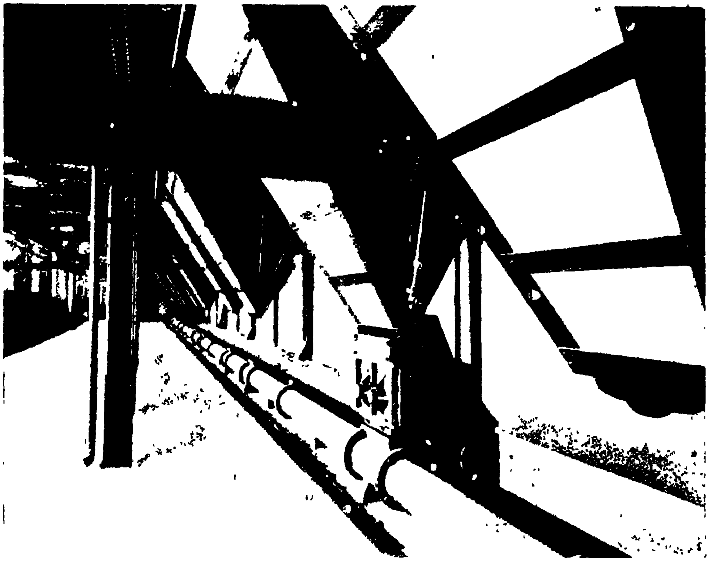

FIG 98 --BABCOCK AND WILCOX PATENT SUCTION ASH CONVEYING PLANT. VIEW IN TUNNEL, SHOWING ASH PIPE, INLET BOXES, HOPPERS UNDER BOILERS, AND ASH BREAKER

Fig. 97 shows an ash tunnel under a Babcock and Wilcox boiler.

In some cases a special system of water troughs or air pipes is installed under the boilers. In the air-pipe system the refuse first falls into a small crushing machine, and is then conveyed through the air pipe to a collector.

Fig. 98 shows a Babcock and Wilcox patent suction ash-conveying plant with ash pipe, inlet boxes, hoppers under boilers, and ash breaker. Large fans create a vacuum, and the air which rushes in at the opening in the pipe under the crusher carries the fine ashes with it. The plant generally consists of an ash pipe which leads into a large ash tank so constructed that carts may be run underneath, a pipe from the ash tank to an air filter and a pipe from the filter to the exhauster. Fig. 99 shows a Bennis patent ash-handling plant constructed on this principle.

In the case of mechanically fired Lancashire boilers the fuel is propelled over the grate by the moving firebars. These firebars move forwards and backwards in alternation, and the refuse falls off the bars at the back into the flue. To remove the refuse a half-division plate, forming the seal between the back bearer bar and the lower half of the furnace, is raised by means of a chain leading to the front of the boiler (see fig. 26). The refuse is then withdrawn by hand with an ordinary rake, and is wheeled away or transported mechanically.

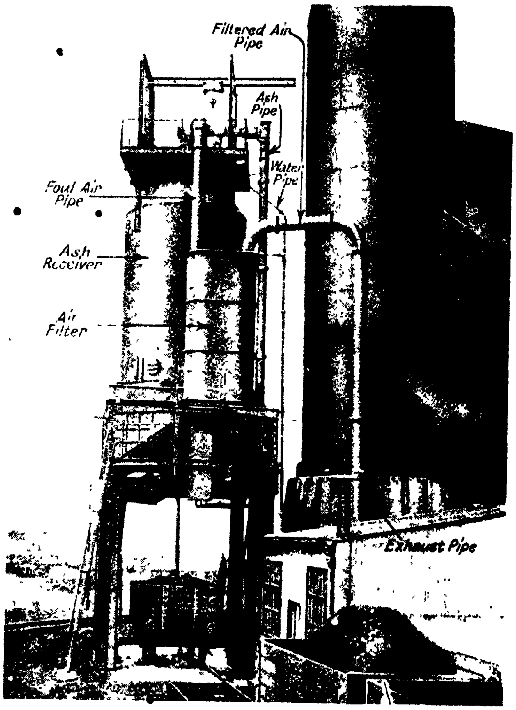

FIG. 99.—BENNIS PNEUMATIC ASH-HANDLING PLANT.

Fig. 100 illustrates an automatic telpher plant for handling ashes from a battery of Lancashire boilers, installed by Messrs. Mitchell Conveyer and Transporter Co., Ltd. The skip is lowered in front of the boiler, and the ashes raked into the skip. The control button is then pushed, the skip is automatically hoisted, and the telpher travels out of the building to the ash bunker, where it is automatically stopped, and the skip discharged. The telpher waits for a period of five seconds and then returns to its original position in the boiler house, awaiting its next load. All these operations are entirely automatic, and can be varied according to any cycle of operation required. The automatic telphers can be used for any purpose where a continuous cycle of operations is necessary.

(*b*) *Disposal.*—The term " boiler refuse " has been used in preference to the words " ash " and " clinker," because in the greater number of cases, especially where boilers are fired by hand, the refuse contains a large percentage of unburnt fuel.

As the boiler refuse is generally carted to the ash heap or disposed of by sale to a breeze merchant, the unburnt fuel constitutes a direct loss. The system employed in removing the refuse will influence any scheme that may be proposed for recovering some of the unburnt carbon. It is, of course, clear that in the case of a large power house, where it is only necessary to draw the vehicle receiving the refuse under the hopper of the ash-handling plant, and the vehicle is filled in a few moments, any interference with this system will mean a loss of time. A fuel reclamation plant must therefore be capable of dealing with all the refuse from such a boiler house as fast as it is delivered.

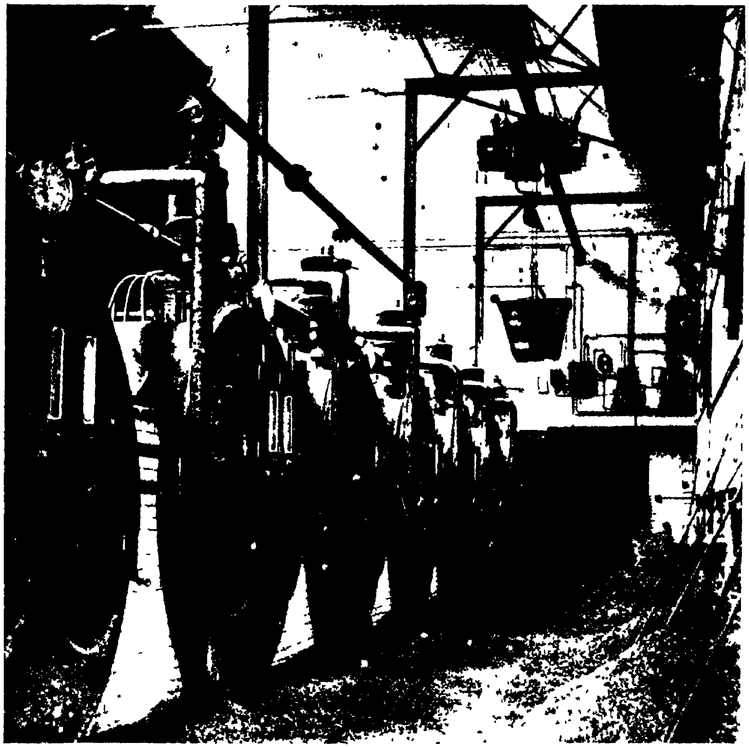

FIG. 100.—AUTOMATIC TELPHER PLANT FOR HANDLING ASHES FROM BOILERS.

No reclamation plant ought to be necessary in such cases, because the boilers are fitted with mechanical stokers which, if properly managed, will discharge the refuse with such a small percentage of unburnt fuel that a reclamation plant would not pay for itself within a reasonable time." The fact, however, is that in most factories at the present time reclamation plants would yield substantial profit, especially where the firing is by hand. That such conditions should prevail is almost inexcusable. Even with hand-fired boilers under good management it is possible to attain high efficiency in combustion, and where mechanical stokers are used no satisfactory reason can be given for the presence of much unburnt fuel in the boiler refuse.

The space under the grate of a water-tube boiler in a modern power house is generally divided, and leads into one or two hoppers, so that the small riddlings and cinders which fall through the grate can thus be collected in exactly the same manner as the ashes, and returned to the boilers. When grates are cleaned by hand, all the unburnt fuel is mixed with the ashes and clinker, and often forms a very high percentage of the total refuse withdrawn from the boiler. Since most of the boilers supplying steam to factories are operated by hand a large amount of good fuel at present thrown away could easily be saved. In this case there is no question of disturbing the usual routine, because the refuse is generally thrown on to the ash heap, where it is out of the way. A reclamation plant situated next to the ash heap would inconvenience nobody, and could be worked when the ash wheelers were not busy assisting in the firehole.

There are two types of machine for recovering coke from boiler-house refuse—namely, dry and wet separators. The dry separators work on the principle that most coal contains some iron which, during combustion, is converted into an iron oxide of sufficiently high magnetic susceptibility to separate the coke from the ashes. The wet separators rely for their efficient working on the difference in the respective specific gravities of the coke and clinker. The refuse is first passed through a rotary sieve which separates the fine dust, and allows the large clinker to pass out at the open end. The remainder enters a vessel, generally a trough, filled to a certain level with some liquid which costs little, but has a high specific gravity, as, for example, loamy water, ammonia liquor, chalk water. The coke floats, and the incombustible matter sinks, each being removed by mechanical means. In one type of machine the removal is effected by two superimposed spiral elevators working in separate compartments.

A further economy may be effected by grinding the incombustible matter and mixing it with suitable binding material, when excellent bricks may be made from the mixture. The cost of making such bricks is very small, and the engineer-chemist, should he be required to supervise this work, will experience little difficulty in obtaining information as to the best methods of manufacture. If such bricks are made, their monetary value, even though they are not sold but are used on the premises, must be credited to the boiler-house account, and not to the general account.

CHAPTER X

FEED WATER PLANT

(*a*) *Purification.* All water used for feeding boilers must satisfy a high standard of purity, and its treatment must be under the strictest supervision. Equal care must be exercised whether boilers are fed with "new" water or with condensed steam, although the method of treatment will differ according to circumstances.

Lancashire boilers are invariably supplied with "new" water, very little, if any, condensed steam finds its way back into the boiler. Water-tube boilers, and all boilers on board sea-going ships, are part of a closed system, in which the same water, with a small percentage of "make up" feed water to cover loss through glands, etc., is used over and over again. Locomotive boilers are supplied with "new" water, with the exception of those fitted to the newest turbine driven engines. Vertical boilers are supplied with water according to their duties. If attached to a plant ashore, they will probably receive the same treatment as Lancashire boilers; if used as donkey boilers on board ship, they may work in connection with a condenser or not. The arrangements in this respect at sea will generally depend on the type and age of the vessel.

We will deal first with the class of boiler supplied with "new" water, which in some instances cannot by any stretch of imagination be described as "fresh" water. The source may be a river, canal, lake, pond, well, or town main. All these waters contain scale-forming matter to a greater or lesser extent, and the kind of treatment required to eliminate this matter is similar for all.[1]

The impurities in water supplies are of three kinds—suspended, colloidal, and dissolved. Suspended impurities may be organic vegetable and animal matter, or inorganic substances such as sand, clay, or other minerals. Colloidal impurities may be present, either as organic colloids (waste, vegetable colours and acids) or as inorganic colloids (extremely fine clay, particles of silica, alumina, and iron oxide). Dissolved impurities are found in all waters in the form of dissolved organic matter, and such inorganic substances as carbonates, sulphates, chlorides, nitrates of calcium, magnesium, and sodium.

The effect of scale is shown in fig. 101, which illustrates the difference in temperature of a furnace when clean, and when covered with ½ inch of scale, the flue gas temperature being the same in each case and averaging 1150° F. The temperature of the clean plate is 350°, and that of the scaled plate 700° F.

Water from a river or canal must also be examined for chemical impurities

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[1] *Water and its Purification*, S. Rideal.

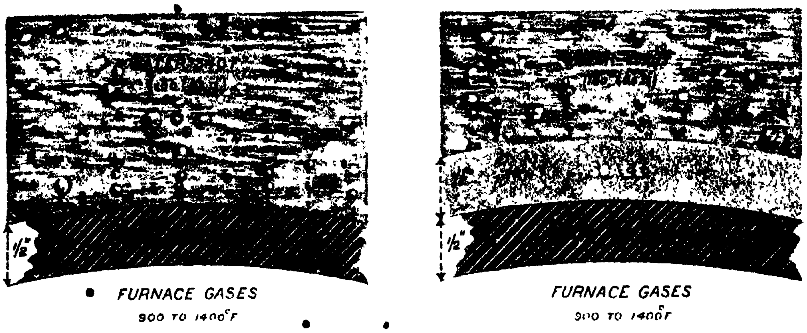

FIG. 101.—TEMPERATURE OF CLEAN PLATE (350° F.) AND OF SCALE-COVERED PLATE (700° F.) WITH THE SAME TEMPERATURE FLUE GASES (900°-1400° F.).

which may have been introduced with the discharge from factories on its banks. Although various authorities are responsible for the cleanliness of rivers and canals, a casual glance at some of them is sufficient to show that every precaution is needed before utilizing the water for feeding boilers.[1]

When water is taken from lakes or ponds — that is, comparatively still water — care must be taken that no organic matter, such as algæ, grass, leaves, or sticks, finds its way into the pipes and chokes the supply system. Organic matter may be held in suspension, and as it very often cannot be seen with the naked eye a special

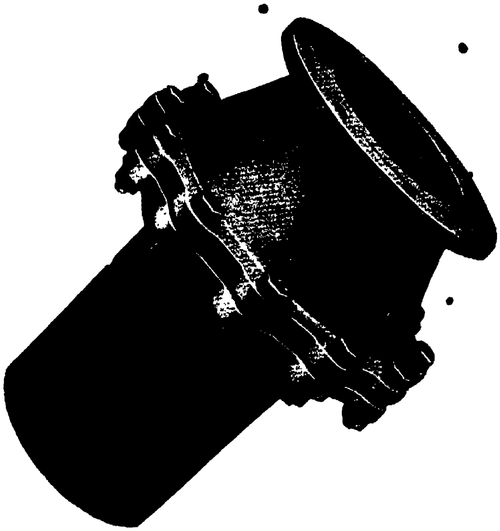

FIG. 102.—PREMIER VALVE BOX (HASTE'S PATENT).

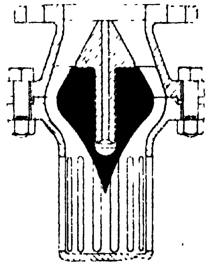

FIG. 103.—SECTION THROUGH A PREMIER VALVE BOX (HASTE'S PATENT).

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[1] *Proc. Inst. Mech. Eng.*, p. 239, 1916.

microscopic examination is necessary. The presence of the organic matter in the boiler as a solid impurity does not matter much, but certain injurious acids are formed which do matter very much, and cause corrosion which is often attributed to entirely different causes. Water drawn from a pond may contain a fair amount of solid matter such as clay or sand, especially in the summer when the water gets low, and the inlet pipe should always be connected to a float so as to be free to rise and fall with the level of the water. The inlet end, fitted with a rose, should be immersed sufficiently to prevent air or floating impurities from being taken into the pipe, but it should also be kept as far from the bottom as possible.

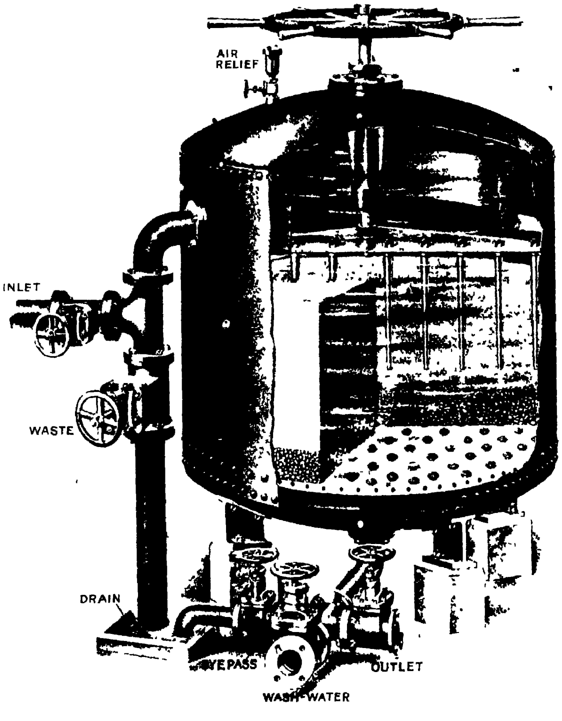

Fig. 101. Paterson Small Pressure Filter.

Fig. 102 shows a type of valve (Haste Patent), made by Messrs. Premier Cooler and Engineering Co., Ltd., which is particularly suitable for inlet feed water ranges, and fig. 103, which is a section through a valve when in the open position, clearly shows the free passage round the valve which allows the water to follow a natural stream-line motion.

If the water is very bad a special filtering apparatus must be provided.

Fig. 104 illustrates a Paterson air-cleaned gravity type quartz sand filter. The filtering medium is a special grade quartz sand resting on a substratum of pea gravel. The water enters the distributing trough, passes downward through the filtering medium, is collected by the manifold strainer system and flows out, as filtered water, through the outlet controller and inspection box into the receiving tank. When choked with intercepted impurities the filter bed is cleansed in place by compressed air, which thoroughly agitates the sand and loosens the impurities. These latter are floated to drain by a reverse current of wash water.

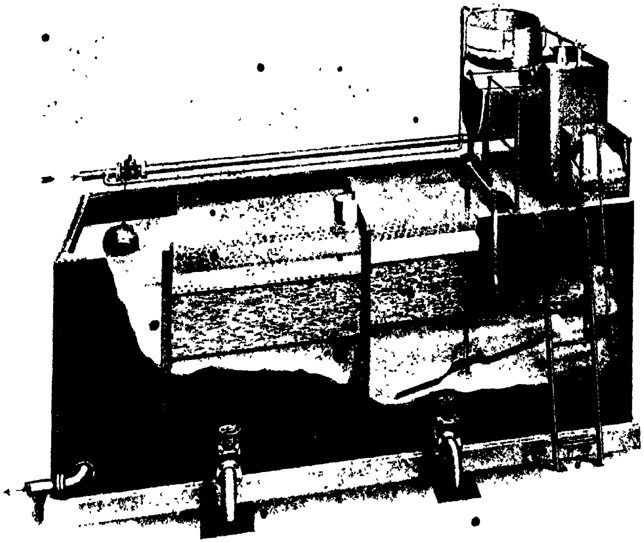

FIG. 105.- PATERSON COLD PROCESS WATER SOFTENER.

The water supplied to the average industrial boiler plant is, as a rule, only softened. The softening may be effected by a cold water softener.

Fig. 105 illustrates a Paterson cold process water softener, in which it will be seen that the hard water is continuously measured by an "Osilameter" which adds the correct proportion of softening reagent. The treated water, after thorough mixture, enters a precipitation tank of sufficient capacity to allow time for the completion of the reaction and the sedimentation of the grosser impurities. The purification of the water is completed by upward filtration through preliminary and final wood fibre strainers. A rotating agitator facilitates the periodical discharge of the impurities accumulated in the reaction tank. The softening reagents are prepared in the slaking and mixing tank carried over the measuring gear. The "Osilameter," which is illustrated in fig. 106, is a twin compartment oscillating receiver mounted on bearings.

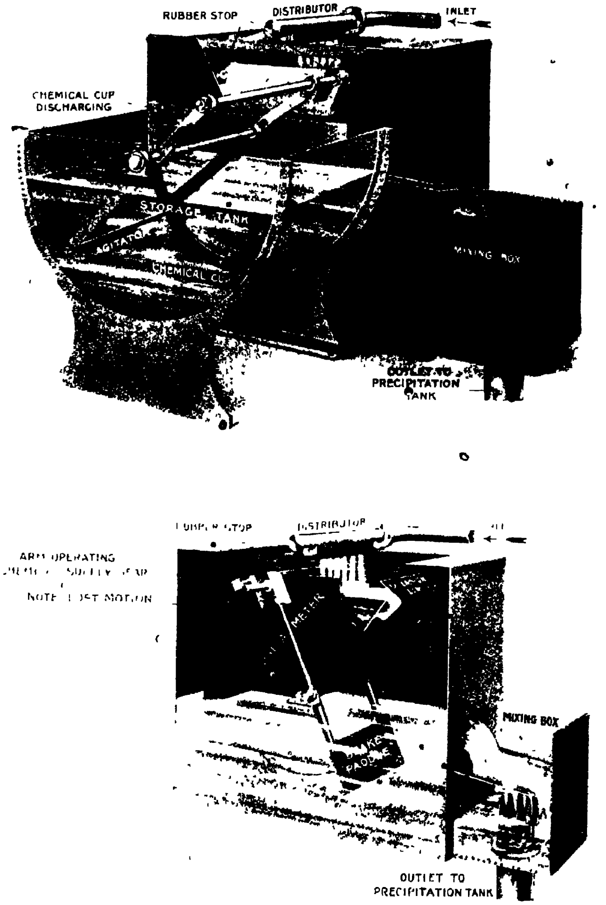

FIG. 106.—PATERSON "OSILAMETER."

Each receiving compartment is provided with an extension lip which, when filled with water (a small surplus overflow from the main compartment), produces a powerful leverage and overturns the receiver. An arm attached to the "Osilameter" moves an agitator in the reagent storage tank, which is provided with two small cups. These cups, holding a definite measure of reagent, are discharged into the mixing box every time the hard water measuring tank is discharged.

The reagents required will depend on the degrees of temporary and permanent hardness in the water.

Temporary hardness is due to the presence of carbonates of lime and magnesia, held in solution by carbonic acid, which convert them into the soluble bicarbonates. When the half-combined carbonic acid gas is expelled—for instance, by boiling—these salts are largely precipitated. A similar effect is obtained by the addition of lime, which combines with the carbonic acid, forming carbonate of lime, and precipitates with the carbonates originally present as bicarbonates. Chalk, when burnt, loses its carbon dioxide and becomes lime or calcium oxide, which, when slaked, is converted into calcium hydrate, and is often used in this connection.

Permanent hardness, due to the presence of sulphates, chlorides, and nitrates of lime and magnesia, is removed by sodium carbonate, generally called soda ash, which converts the dissolved sulphates of lime and magnesia into carbonates, leaving the soluble and non-scale-forming sulphate of soda. In special cases when calcium sulphate, chloride, or nitrate is present in chemically equivalent proportion to the temporary hardness, caustic soda treatment must be applied.

The chief impurities in ordinary water are calcium carbonate and magnesium carbonate, both of which cause temporary hardness, and are removed by lime; and calcium sulphate, causing permanent hardness, which is removed by soda ash (sodium carbonate).

Reference has already been made to closed feed systems in which the steam is condensed and then pumped back into the boilers. Such systems are used, as has already been mentioned, in connection with water-tube boilers and Scotch marine boilers. Two reasons have influenced their adoption with water-tube boilers. In the first place, these boilers, having a very high rate of evaporation, require feed water absolutely free of all scale-forming matter, as, if any scale is allowed to form inside the tubes, the rate of heat transmission is retarded, and trouble, such as burnt tubes, soon follows. In the second place, water-tube boilers in large electric power stations generally supply steam to turbines, and as the efficiency of a turbine largely depends on the vacuum maintained by the condensing plant, it is only natural that the steam which has been condensed should, as water, be pumped back into the boilers.

The water which has to be added to boilers working in a closed system must, of course, be pure, and on shore this is ensured by passing the water through either a hot or a cold process water softener. On board ship such apparatus is useless, on account of the high percentage of sodium chloride in sea-water, and all " make-up " feed water, if the fresh water carried in the double bottom has been used, must be evaporated. An evaporator consists of a closed vessel fitted with a series of steam coils for boiling the water contained therein.

Fig. 107 shows a Weir patent evaporator. It will be seen that the apparatus is fitted with a safety-valve, blow down cock (in addition to the necessary fittings for introducing the salt water to be evaporated), steam valve, gauge glass, heating steam regulating valve, condensed steam drain, and salinometer cock. It is designed in such a manner that the copper coils may easily be removed, scaled, and put back again. Calcium sulphate deposits at a temperature of about 270° F., and an evaporator should always be worked at a pressure corresponding to a slightly lower temperature than this. This type of evaporator may be constructed to use either

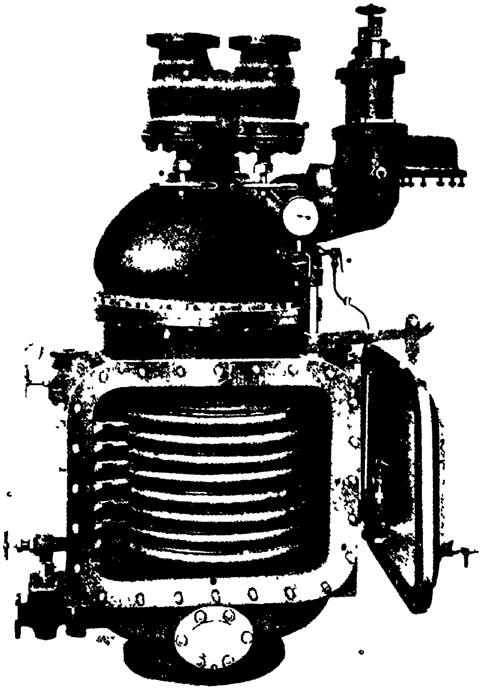

FIG. 107.—THE WEIR VERTICAL EVAPORATOR, "LUNETTE" TYPE

live steam, steam from the intermediate pressure cylinder, or exhaust steam. The steam from the boiling sea-water is sent into either the main or the auxiliary condenser, from which it flows in the ordinary way to the feed pumps.

Unfortunately, steam becomes contaminated with the oil used for lubrication purposes, and with the ever-increasing temperature of steam, due to the use of superheaters, trouble from this cause is on the increase.[1] Where turbines are installed there need be no trouble, because a turbine has an enclosed pressure lubricating system; but with reciprocating engines the problem is much more serious. For reciprocating engines, lubrication is necessary, and although only the best mineral oil must be used, and that very sparingly, a certain amount of this is introduced into the cylinders, and will mix with the steam. Special apparatus for dealing with the oil, which is in the form of very fine particles, then becomes necessary. The oil, which assumes the form of a very fine emulsion, must be separated from the condensed steam before the latter is pumped back into the boilers, because the least trace of oil in a water-tube boiler is more dangerous even than a bad thickness of scale. The separation may be effected either whilst the oil is held in suspension by the steam or after the steam has been condensed, but removed the oil must be. Mr. C. E. Stromeyer, in a paper on "Distortion in Boilers due to Overheating," states: "A film of grease $\frac{1}{100}$ inch thick offers resistance to the passage of heat equal to a steel plate 10 inches thick. In other words, grease offers a thousand times the resistance of steel to the passage of heat."

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[1] *Theory of Emulsions and Emulsification*, Dr. W. Clayton

There are several methods of removing the oil. Those employed when the steam has been condensed are as follows:

(1) The condensate may be passed through a cloth filter. In this type of filter a considerable length of special filter cloth surrounds a series of perforated cylinders, and the feed water is forced through the towelling. The compactness of this apparatus has caused its general adoption on board ship.

(2) A chemical reagent may be used to eliminate the oil. Fig. 108 shows a Paterson oil eliminator with quartz filter.

The oily condensed steam enters the measuring chamber and overflows through a rectangular or V-notch discharge weir. A large float resting on the water in this weir chamber controls the position of two long tapered valves giving annular orifices which discharge the reagents in accurate proportion to the amount flowing over the weir. The reagents used are sulphate of alumina for the coagulation of the oily particles, and soda ash for the neutralization of the alumina. The greasy water and the reagents are thoroughly mixed in the baffling trough before passing into the reaction and precipitating tank, where the bulk of the coagulated impurities is arrested by filtering upwards through wood fibre, the final purification being effected by downward filtration through quartz sand.

(*b*) *Exhaust Steam Economy.*—Industrial boiler plants are generally characterized by black smoke and volumes of escaping steam; both are unnecessary, and denote waste. The former should be eliminated, as already explained. The latter may be utilized in many ways.

The steam could, of course, be condensed, but most plants are not fitted with a system of exhaust steam pipes leading to a condensing plant, because the cost of installation and upkeep is considered too heavy. There is no doubt whatever that in most cases a marked economy would be effected by condensing, and it should also be remembered that the wear on a machine working in conjunction with a condenser is far less than when exhausting to atmosphere.

If not condensed the steam may be collected in a receiver, de-oiled by passing it

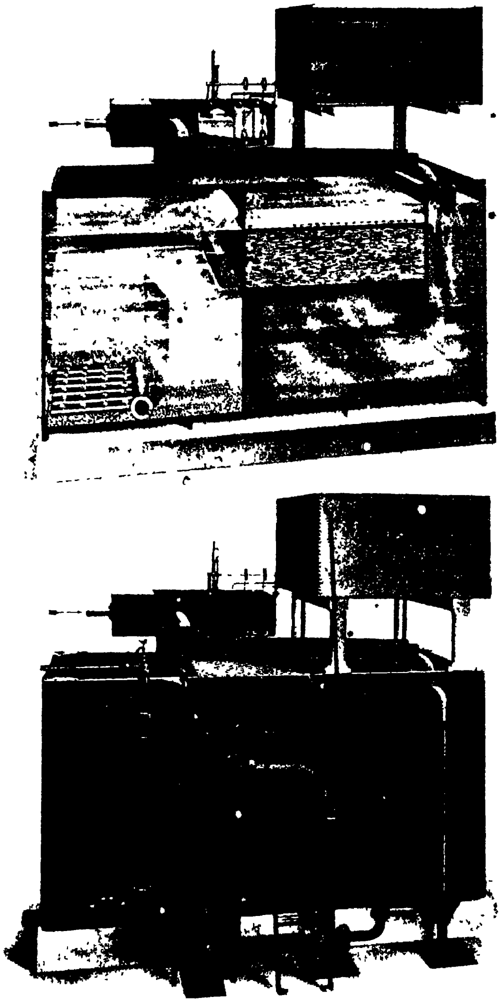

FIG. 108.—PATERSON OIL ELIMINATOR WITH QUARTZ FILTER.

through an oil separator, and supplied to a low pressure or mixed pressure turbine. This plan has been adopted to a large extent by collieries, where a great quantity of exhaust steam is available from the winding engines, fan, air compressor, haulage engine, etc. The steam is passed through an oil separator. Fig. 109 shows a "Premier" oil separator with the elements partly removed.

The internal parts consist of perforated baffle plates, and specially rolled angle irons, so arranged that the steam impinges on the sharp edges of the angles, and thus any oil or grease held in suspension is deposited on the same. The deposited matter finally flows down the angles to the bottom of the separator, whence it is extracted in due course.

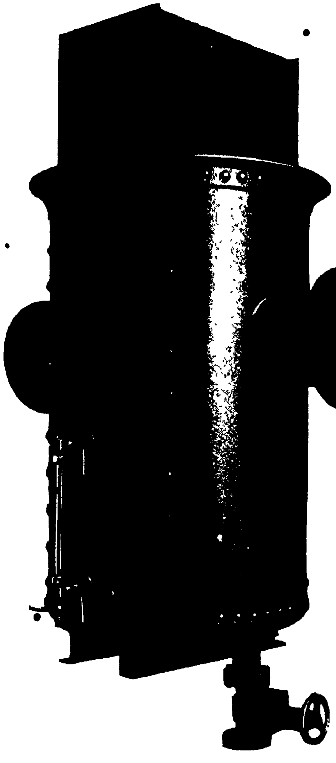

FIG. 109.—"PREMIER" OIL SEPARATOR WITH COVER REMOVED AND INTERNAL ELEMENTS PARTLY WITHDRAWN.

In cases where the quantity and pressure of the exhaust steam are not sufficient to warrant the introduction of special plant, all the exhaust steam from engines, pumps, and process machines, together with condensed steam from steam traps, should be collected as far as possible and led into a receiver or tank, sometimes called a hot-well. This receiver must be fitted with a safety-valve, air-escape, and cocks for filling and emptying. An old condemned Lancashire boiler from which the flues have been withdrawn, and the openings closed with circular plates, may well be used as a receiver. Cold water should enter the top and fall into a perforated box, the arrangement being shown in fig. 110.

The mixture of exhaust steam and condensed steam will enter in such a manner that the full force of the exhaust may strike the incoming water as it is split up into particles by splashing against the perforated baffle box. The steam will be able to surround the drops of water and, mixing with them, to raise uniformly the temperature of the resulting feed water. Also the air in each globule of water, expanding more than the water, will burst each globule and escape as free air through the pipe provided.

Theoretically, a safety-valve is not necessary, but the air-escape valve may become choked, and in that event, though at no other time, some high-pressure steam is sure inadvertently to find its way into the receiver, and there will be danger of an explosion. The heater is only a crude piece of apparatus, but it serves the purpose of turning the heat in exhaust steam to good account, and costs very little, as it can be made by the repair shop staff. If the exhaust steam contains a considerable percentage of oil it is advisable to combine the duties of water softener and feed water heater by installing some type of hot process softener.

Fig. 111 illustrates a Paterson hot process water softener. When the steam is sufficient to heat the water to boiling-point, this process will automatically solve the problem of temporary hardness, and only the permanent hardness need be considered. There is seldom sufficient steam for this, and chemicals must therefore be added, as with the cold water softener already described.

The importance of eliminating all the air from feed water before it is pumped into the boilers cannot be emphasized too strongly, and this is especially necessary with boilers worked on a closed system that is, supplied with condensed steam. As has already been mentioned, marine boilers and water-tube boilers work on a closed system, and where they are used it is essential that the air be liberated The Weir patent contact feed water heater illustrated in fig 112 is the standard apparatus used on board ship to heat the feed water and eliminate the air.

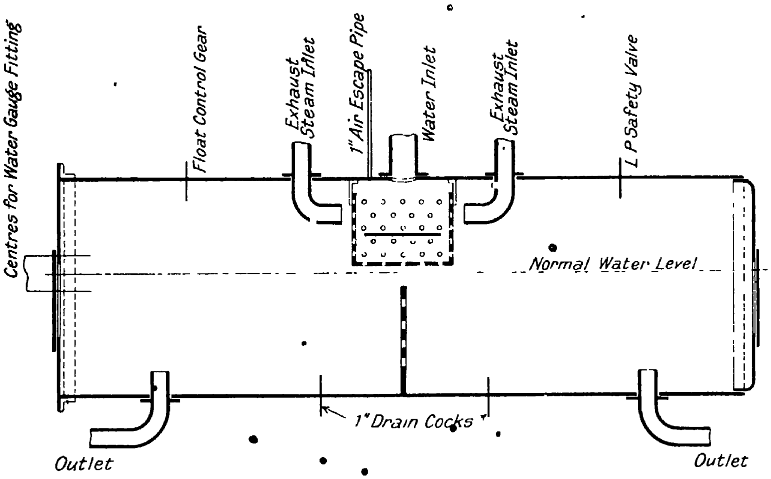

Fig. 110.—Diagram of Old Lancashire Boiler converted for use as an Exhaust Steam Feed Water Heater

The steam used for heating the water is generally taken from the steam receiver on the medium pressure cylinder, and the water is discharged into the heater under pressure by the feed pumps worked by the engines. The air escapes through a small cock, which can be adjusted so as to be open either to the atmosphere or to the condenser. When the cock is open to the condenser the pressure in the heater is reduced and, as the boiling-point of water varies with the pressure, the temperature of the water for a given supply of steam will be higher than when the cock is open to the atmosphere.

The heater is placed as high as possible in the engine-room, so that a head of water of 30 feet or more is obtained above the pumps. This, of course, has the

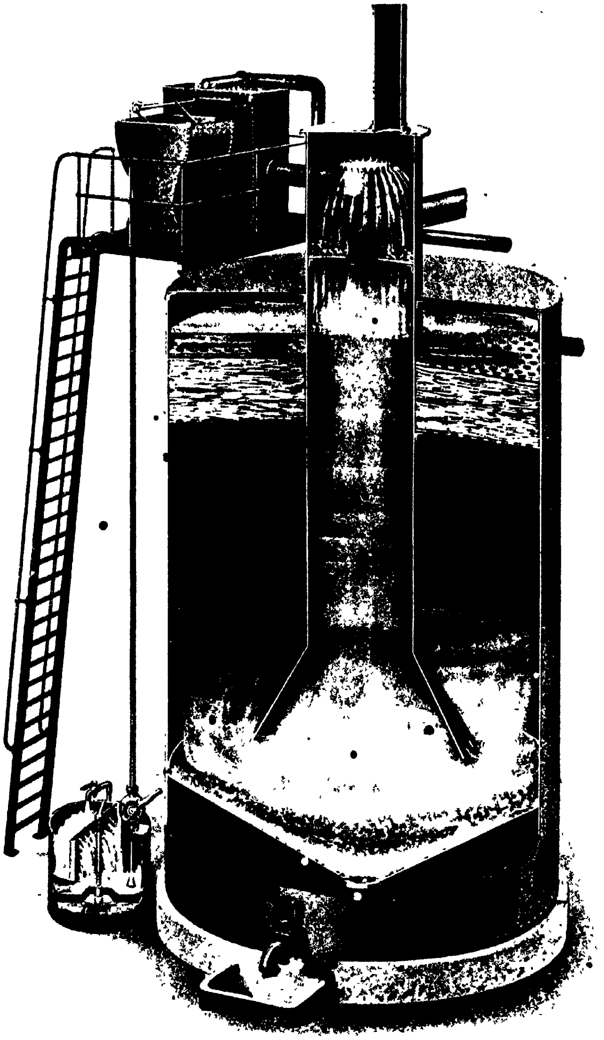

FIG. 111.—PATERSON HOT PROCESS WATER SOFTENER (SHOWING HEATER TYPE).

opposite effect to that already stated, and the increased pressure raises the boiling-point so that the pumps will work smoothly and not commence knocking, due to the ormation of steam in the pump barrels, and feed water at a temperature of 20° may be delivered to the boilers for weeks on end.

With water-tube boilers on shore the very latest practice is to work on similar ines to those adopted with Scotch marine boilers at sea and to use the heat in the lue gases for heating the air necessary for combustion. This course is being

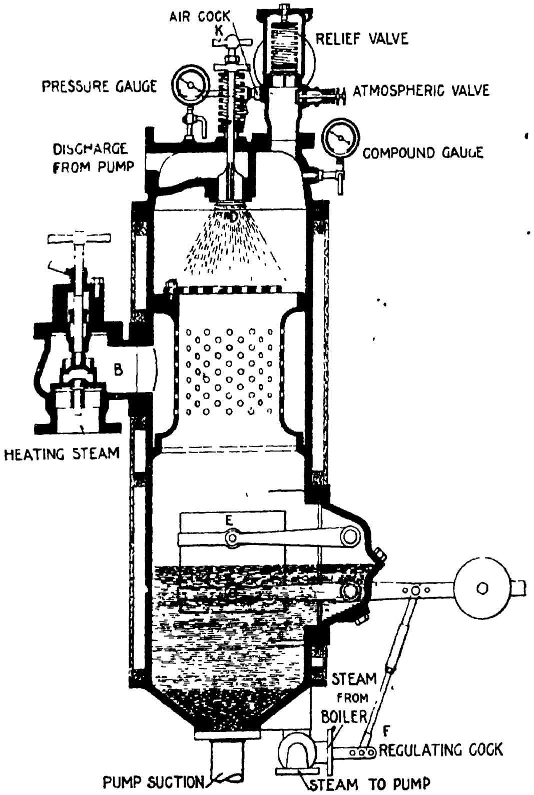

Fig 112.—Weir Direct Contact Feed Water Heater and Automatic Regulating Gear

suggested on account of the very high pressure for which these boilers are designed, and although at present cast-iron tri-tube economizers, as already described, are quite safe and the steel tube economizer will, as far as strength is concerned, meet all the requirements of developments in the immediate future, there are boilers under construction, and working as experimental units in very small sizes, generating steam at about a thousand pounds per square inch.

In any case it will be necessary to de-aerate the water, whether it is pumped straight into the boilers or passed through steel tube economizers. Otherwise the nascent oxygen liberated from the feed water will cause serious corrosion. Corrosion when once set up quickly eats away the tubes and also the tube headers, rendering very expensive replacements necessary. From the foregoing it will be gathered that a plant which will successfully de-aerate feed water and prevent corrosion trouble is a necessity where steel tube economizers are used. If the Weir system is not adapted for use on shore, other arrangements must be made.

Fig. 113 shows Messrs. Hick Hargreaves' patent de-aerator.

This apparatus can be applied to existing plants, and consists of a de-aerating chamber, air ejector, and feed heater. The operation of the de-aerator is as follows:

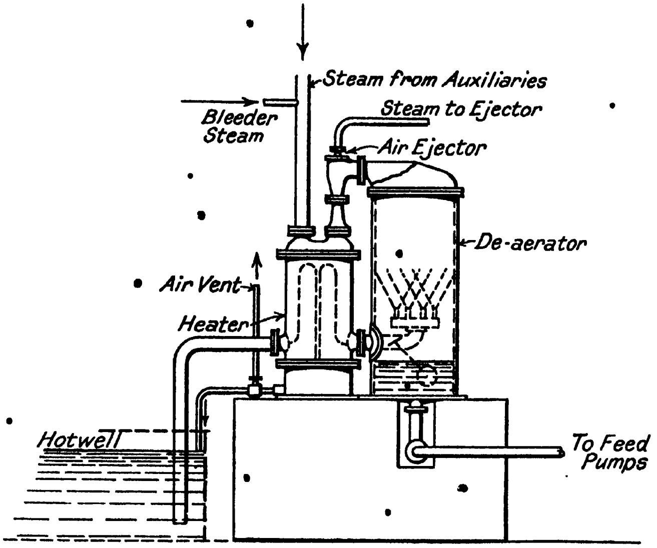

FIG. 113.—HICK HARGREAVES DE-AERATING PLANT FOR FEED WATER.

Water is forced by atmospheric pressure from the hot-well into the de-aerator. On its way it is heated to a suitable temperature by the steam discharged from the air ejector, mixed with steam from auxiliaries about the plant, or bleeding steam, as may be found necessary. The water is sprayed in the de-aerator by means of specially designed jets which break it up into fine particles, thus liberating the air and enabling it to be extracted by the ejector. The de-aerated water falls to the bottom of the vessel, whence it flows to the inlet side of the pump.

In the ordinary industrial boiler plant live steam should never be used for heating feed water, because there are plenty of other and more economical methods of achieving this purpose.

In some special cases it is advisable to use a surface feed water heater for raising the temperature of the feed water. Surface feed water heaters are very similar to surface condensers. They consist of a series of tubes secured between two tube plates. The steam generally passes through the tubes and the feed water to be heated around them. The arrangement varies according to whether high-pressure or low-pressure steam is used. Surface feed heaters possess two advantages the first is that the steam, together with the water that is formed by condensation, is kept separate from the water to be heated, and the second is that the feed water temperature may be accurately regulated without any waste of heat. Exhaust steam containing a considerable amount of oil or other impurity, if coming from special high-pressure process machinery, may be used without fear of contaminating the water being heated A special type of heater for use on shore is made by Messrs. Royles, and is known as the Row patent feed water heater, due to the particular shape of the tubes used in its construction.

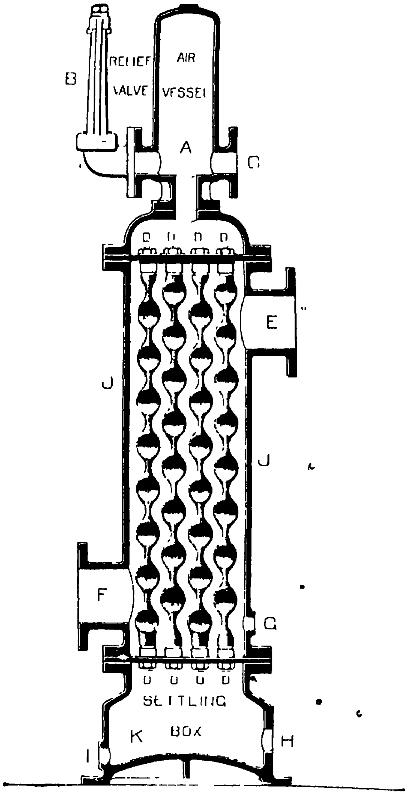

FIG 111 – ROYLES' FEED WATER HEATER WITH ROW TUBES.

In the type shown in fig. 111 the water passes through the tubes, but a second type is also made in which the steam passes through the tubes. The first type is designed for use where exhaust steam is to be utilized, whilst the second is suitable for high-pressure steam. Space does not permit of a detailed description of feed water treating plant, and the methods adopted in utilizing exhaust steam, but the engineer-chemist must be conversant with the few details here given in order to supply the boilers with suitable feed water and, incidentally, to use all the exhaust steam that may be available for the service of his department

CHAPTER XI

PIPE SYSTEM

(a) *Steam Pipes.*—Once a steam pipe system has been installed it is apt to be forgotten, and yet any failure, such as a burst pipe or cracked flange, will cause considerable inconvenience, and may result in loss of life. In view of the high pressures at which modern boiler plants are worked, and the high temperature due to superheating, steam pipes can no longer be trusted to take care of themselves.

A steam pipe, as supplied by the leading makers of repute, is an article which ranks with the finest machinery made. The steel must possess special qualities, and the workmanship must be beyond reproach. The pipe itself is therefore worthy of care.

Those who have been intimately associated with steam at a pressure of 215 pounds per square inch, escaping at 480° F., will know that *prevention is better than cure.* A mistake very often made is to force a pipe into position in order to make the flanges meet. The conditions under which a steam pipe works are quite sufficiently severe without the addition of any unnecessary stresses. Pipes should always be lined up carefully, and not erected by supporting them "anyhow," inserting the bolts in all the flanges and then tightening the nuts when all the pipes have been connected, in order to "draw them up." If the joints do not leak when steam is turned on, it is more good luck than good management in such cases.

A fault with many pipe systems is that they are far too rigid, no allowance having been made for expansion. In order to allow for the free movement of pipes, expansion bends should be inserted; the type of bend adopted depending on the space available and size of the pipe. Fig. 115 illustrates various kinds of expansion bend.

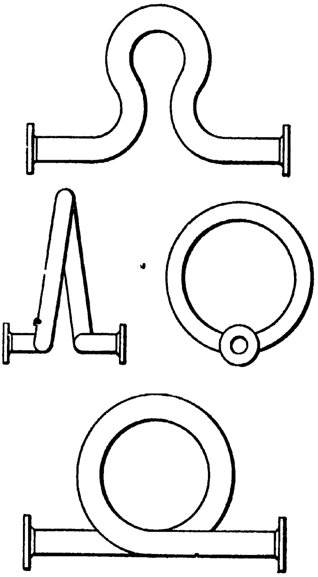

FIG. 115.—EXPANSION BENDS.

In special cases it is advisable to adopt a diaphragm as shown in fig. 116, or an expansion gland as illustrated by fig. 117.

When reading official accounts of enquiries held to ascertain the causes of pipe or stop-valve failures the writer has been impressed by the number of instances in which the history of the pipe or valve is not known. A record should be kept of the history of all the important steam pipes, including the name of the maker, the pressure and the date at which they were tested, particulars of their size, previous trouble experienced with them, and any other data worthy of note. A complete set of drawings showing every steam pipe should be kept in the engineer-chemist's office.

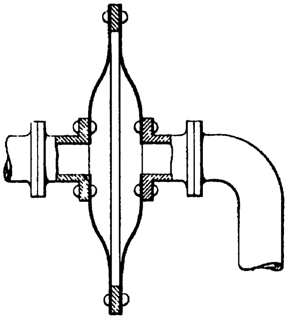

FIG 116.—EXPANSION DIAPHRAGM.

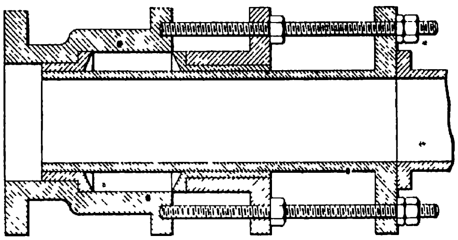

FIG. 117. EXPANSION GLAND

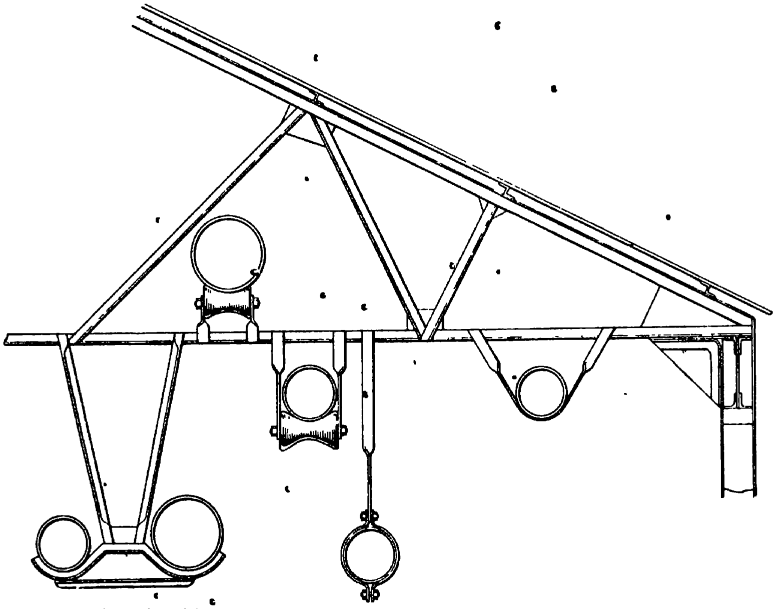

FIG. 118.—METHODS OF SUPPORTING STEAM PIPES FROM A ROOF TRUSS.

On a large plant it is almost impossible for a single individual to know by heart where every pipe leads and its particular function, and yet in case of emergency such information is required at a moment's notice. If the works are not to be stopped, some alternative to the usual method of supplying steam may have to be found, and a thorough knowledge of the plant, together with the assistance of an up-to-date set of drawings of the whole pipe range, will reduce the delay to a minimum. Oftentimes, if you ask an employee who has been with a firm a number of years where a certain pipe leads, he either "does not know" or makes a guess which is wrong. Especially in old plants, where the size of the boiler plant has been increased from time to time, the steam-pipe system is very complicated. Dips and bends are often more numerous than the lengths of straight pipe. Condensed steam will collect in all such pockets, and every encouragement for water hammer exists.

Fig. 120 shows how condensed steam collects in a valve.

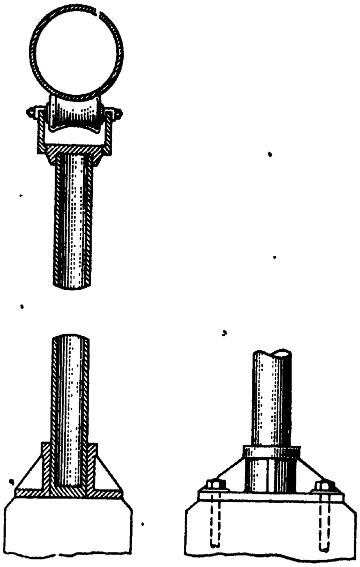

FIG. 119.—PIPE SUPPORT.

It may safely be said that water hammer has caused more fatal accidents than anything else, not excluding boiler explosions. Drain pipes should be fitted wherever necessary, but this method of overcoming the difficulty is only a makeshift. Power plants should be so designed that steam cannot accumulate in the pipes. In any case, all the drain pipes should be collected and led back to the hot-well. Every time a drain is opened a large quantity of water, generally good hot water, is wasted, which means so much fuel literally thrown away. In an old plant a slight reorganization of the pipe system will soon pay for itself, and new plants are *theoretically* correct.

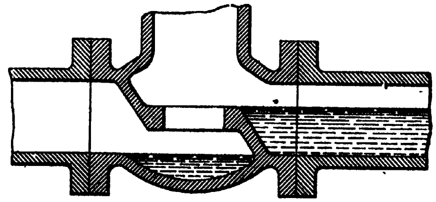

FIG. 120.—FORMATION OF CONDENSED STEAM IN A PIPE LINE.

Fig. 121 shows the necessity of fitting a drain cock at A, and fig. 122 shows the effect of condensed steam in reducing pipe area when coupling a boiler stop-valve with the main steam range in the manner shown. All steam-pipe systems should be fitted with steam-traps and safety-valves kept in good working order, the number depending on the length and complexity of the pipe range. It is not safe to rely on the boiler safety-valve alone. A simple calculation will show the kinetic energy a pound of water possesses when travelling at the velocity of steam rushing into an empty pipe.

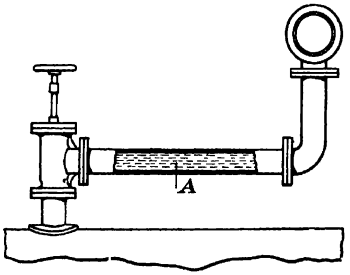

Fig 121 - Drain Cock necessary at "A" to Prevent Water Hammer.

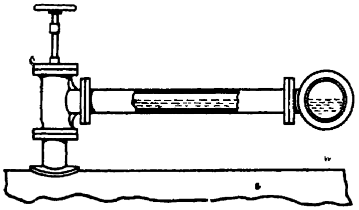

Fig. 122 – Effect of Condensed Steam in Reducing Pipe Area

Finally, there is the question of the efficient covering of all steam and hot-water pipes. It is not yet sufficiently realized how enormous is the waste when steam pipes are not efficiently lagged. The lagging of pipes may be good, bad, and indifferent. There is only one quality that is worth purchasing, and that is the best

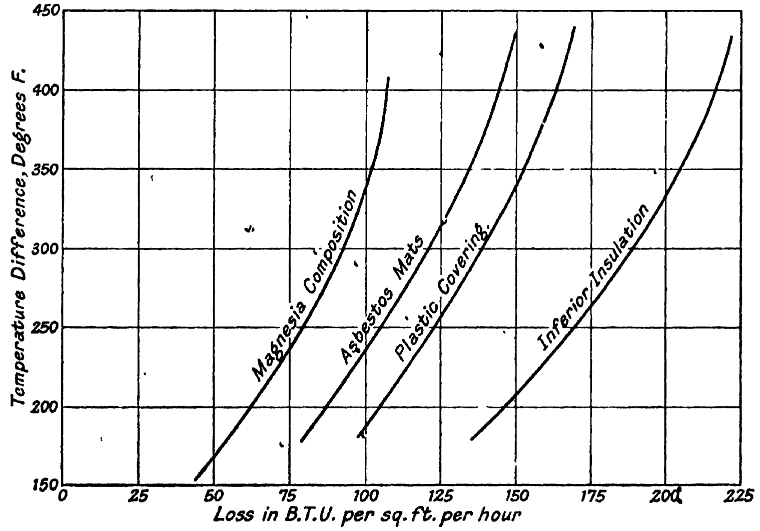

Fig. 123.—Comparison of different Insulating Materials.

Fig. 123 shows the insulating properties of several substances. Pipes are often lagged with inferior compositions of which it can only be said that they hide the pipes from view. Poor lagging does not bind with the metal; and moisture creeps underneath and commences corrosion, which goes on unseen and therefore unsuspected.[1] When the lagging becomes saturated it falls off in large lumps. Pipes must be lagged with a composition containing at least 85 per cent. magnesia. The methods adopted when covering pipes are dealt with in the second part of the book (Chapter XXIII.).

(*b*) *Water Pipes.*--The water pipes, with the exception of the feed and blow down range, need not be so great a source of anxiety as the steam pipes. In the case of steam pipes the trouble may be instantaneous, due to a slight disturbance in a pipe already overstressed. The material will give very little warning in the way of steam leaks, " blow holes," etc., before the accident happens. With water pipes it is different, because the metal before it fails has generally suffered a preliminary weakening due to corrosion, and symptoms of this can be discovered beforehand.

If pipes are carefully examined at regular intervals, or whenever an opportunity presents itself, they will give little trouble.

The blow-down pipe system requires special attention. Often the connection between the boiler and the pipe range is far too rigid. This is especially the case with Lancashire boilers, it being the common practice to connect each boiler, by mean of a cast-iron elbow pipe and a parallel slide blow-down valve, to the blow-down range running parallel with the front of the boilers. Since the boilers are fixed rigidly, it follows that the expansion which takes place in the blow-down pipe tends to push the main pipe away from the boilers. This pipe is, however, held rigidly in place by the elbows from neighbouring boilers, generally spaced about 14 feet centres, and in addition it is often surrounded with ashes and dirt which have set hard, so that it is little wonder trouble is experienced. The blow-down pipe should be of cast steel specially treated to resist the very abrasive action of water laden with sediment which rapidly wears the pipe away. It must be perfectly clean outside, with special packing if it passes through the front of the boiler setting. Modern practice is to recess the brickwork so that the pipe is continually free for inspection.

Wherever possible a suitable bend or expansion pipe should be inserted between the blow-down cock and the main pipe line. Where a blow-down cock is fitted —a valve is better—the operating handle must have a small projection on one side, and the cover of the cock must have a special guard attached so that the handle can only be withdrawn when the cock is shut.

Of equal importance is the feed-pipe system. In very few cases on shore are there two distinct systems of feeding the boilers, although on some of the older plants several pumps are to be found which would serve very well as a stand-by if overhauled, and a secondary pipe line could easily be provided. The value of two independent ranges can hardly be overestimated in view of the fact that unless a boiler is being constantly supplied with water it has to be stopped.

The most important matter in connection with the safe working of the pumps is that the feed range should be supplied with a well-designed spring-loaded relief valve.

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[1] *Report on Insulating Materials*, Engineers Standards Committee.

Fig. 124 shows a relief valve, through which, in the event of all the feed check valves being shut, the water will be able to escape. On a fairly large boiler plant, where several firemen work on each shift, it may happen that all the valves but one may be closed, and that one may only be partially open, and the pumps may not have been slowed down. The result will probably be that several joints will give way under excessive pressure, making unnecessary work. The relief valve should not be placed in some out-of-the-way position where it is likely to become rusted and so to fail to lift when it should. It should be fixed in a position that is constantly under observation. If it commences to lift when in such a position, someone will probably get wet, and run round to slow down the pumps.

Although this means a waste of water, it is better not to fit the safety-valve with a cover and outlet branch connected with a pipe to the hot-well, because in that case firemen will not notice when it is lifting. Escaping steam presents a different problem, because there is always the noise, which gives sufficient warning.

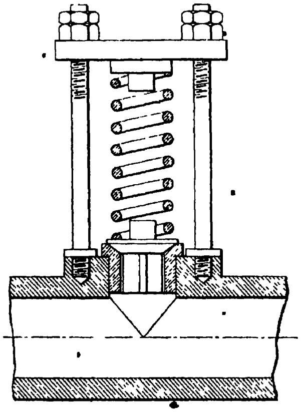

FIG 124.—SPRING LOADED RELIEF VALVE FOR FEED PIPE RANGE.

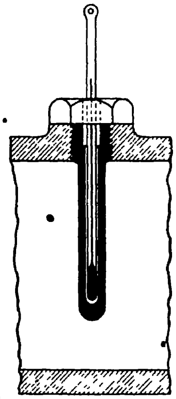

FIG. 125.—THERMOMETER POCKET.

All feed pipes should be well lagged in order to minimize the drop in temperature which occurs whilst the water is passing from the economizer or feed-heating plant to the boiler. In order that the temperature of feed water passing through the pipes from one apparatus to another may be ascertained, a suitable thermometer must be provided in the pipe line. The thermometer pockets should be of stout construction and dip well into the pipe to make sure that the thermometer itself is in the centre of the flow of water.

Fig. 125 shows such a thermometer pocket.

Feed pipes often become coated with scale to such an extent that the actual passage through the pipe is very small compared with the original internal area. Whenever an opportunity occurs feed pipes must be taken down and thoroughly cleared. Where there are two independent ranges, this presents no difficulty, and the work can be undertaken in sections whenever a boiler is " off " for cleaning.

It is safer to insert blind flanges than to trust to the tightness of valves. Many accidents have happened through someone opening a feed check valve when men were at work in the boiler. The least the engineer-chemist can do is to remove the hand wheel and send it to the store for safe-keeping until the boiler is ready for work once more.

On many old plants a very complicated system of feed pipes exists, and with a little alteration two independent ranges can be made. Collieries, in particular where large quantities of water are pumped out of the mine, have this characteristic.

The water from the mine is often salt, and almost invariably brackish, and if discharged at random often returns to the source from which the boiler feed water is taken, causing no end of trouble. In some cases an emergency connection exists between the feed-pipe range and the discharge pipe from the pit pumps. In such cases a blind flange must for safety be inserted in front of the valve, because in time all valves corrode and commence leaking.

A small hot-water pipe, taken from the feed-heating plant or other exhaust steam tank, sometimes supplies water to such a department as the bottle-cleaning department. The amount of water so supplied must be controlled by the engineer-chemist, because otherwise a wholesale waste of good warm water will take place, and heat will be lost which might have helped to increase the efficiency of the boiler department.

In a large installation steam may be supplied to special water-heating plant, and in that case the matter will probably not concern the engineer-chemist, because his department will not be responsible for the use of the steam once it has left the boiler house.

In many cases small steam or hot-water pipes have been erected to meet special requirements—particularly since 1914. When these requirements had no longer to be considered, the pipe line was not removed and, becoming corroded, it commenced to leak. Although the range is nominally out of use, a small trickle of hot water goes on unknown, and therefore unchecked, from one month to another. On a properly organized plant no leaks of any description will be permitted, and only unavoidable losses will be incurred.

SECTION IV.—MANAGEMENT OF STAFF

CHAPTER XII

ROUTINE OF BOILER-HOUSE STAFF

(*a*) *Fixed Time-Table.*—The routine of working a boiler plant is of the greatest importance, and surprisingly great improvement can be effected with no other change than the institution of an organized system of working in a plant which has hitherto failed to cope with the demands made upon it for steam production. Most industrial boiler plants suffer from lack of scientific control, for the reason that very little executive attention is devoted to this department of a factory. The manager may pay the boiler house an occasional visit, if he happens to be anywhere near, but that is of no use whatever.

One of the chief functions of the engineer-chemist is to institute a fixed program and to see that the men adhere strictly to his instructions.[1] It is immaterial whether the plant be small or large, a fixed time-table is absolutely necessary to obtain economical results. The engineer-chemist must organize the work to be done in his department, and not allow the correct working to be dependent on the goodwill and exertions of the mechanic or leading fireman Amongst his duties the engineer-chemist must include the supervision of firing the boilers, whether this be done by hand or mechanical means, the correct adjustment of superheaters and economizers, regulation of draught, and the supply and consumption of suitably treated feed water. He must so organize the handling of fuel that none whatsoever will be burnt without being recorded, and he must superintend the disposal of ashes.

Further, he must supervise the testing of fuel, water, and all consumable stores, and be responsible for the correct working of all instruments. He must undertake such tests in connection with the whole plant or its constituent parts as he may think necessary, and must effect all possible economies. He must keep strict record of every item in connection with his department—wages, renewals, consumable and non-consumable stores, etc. He must pay strict attention to the time-keeping of his staff, and interest himself in the latest scientific developments in steam production, so that when any reorganization or renewal of the plant is under consideration, he may be in a position to give the directors any information they may desire. In short, his duty is to run the department in such a manner that the closest investigation will disclose no serious defects.

The aim of the engineer-chemist is to supply steam at the factory stop-valve, which shall always be up to the required standard, of constant pressure, and, if superheaters are fitted to the boilers, of constant temperature also. In making a fixed time-table for the boiler-house staff he must have regard to the loads which he will be called upon to carry. In a boiler plant which works under a steady load, such as that on a ship during a long journey with steady weather, or in a factory in which the demand for steam is practically constant from day to day, the matter is quite simple. The men will work in shifts (called "watches" on board ship), and the routine will go on undisturbed, with the exception, in the case of the factory, of the week-end.

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[1] *The Philosophy of Management*, O. Sheldon.

Comparatively few boiler plants on shore work under such conditions, and a fluctuating load is the general rule. The fluctuation may only be slight, as in an average cotton mill, but in many cases it will be more pronounced. The boiler house of an electricity station is a good example of fluctuation due to the necessity of carrying peak loads at special times of the day.

Fig. 126 shows the load for one year on a boiler plant serving an electric power station in a residential area. A power station serving electric railways will have a heavy load during the rush hours, when large numbers of passengers have to be transported. Very severe conditions prevail in breweries, where the demand for steam is quite small until the large mash pans, holding hundreds of gallons of cold water, have rapidly to be brought to the boil.

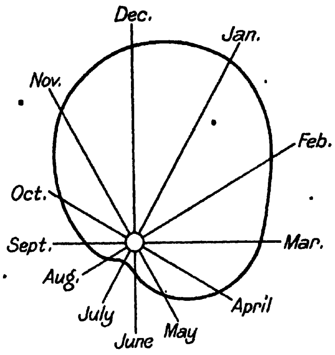

FIG. 126.—LOAD FOR ONE YEAR ON BOILER PLANT ATTACHED TO AN ELECTRIC POWER STATION.

The engineer-chemist will study the requirements of the factory very carefully, and according to the demand for steam draw up a suitable time-table for the boiler-house staff, taking care that it shall be adaptable to the changing conditions likely to be experienced.

Fig. 127 shows the fluctuating load on the power station of a large works on a day in June, and fig. 128 shows similar fluctuations, but with a higher load, being a record of the same power station on a December day.

Conditions vary greatly from industry to industry. Most factories work only during the day-time, from six or seven o'clock in the morning until five or six at night. During this period there may be two shifts of firemen at work, the change-over occurring about midday. Such cases present no particular difficulty. In some factories there is a very heavy load all the morning, and scarcely any load from midday onwards. This happens where the morning is devoted to boiling some substance, and in the afternoon the apparatus is cleaned for the next day's work. Under such conditions it may be advisable to make the morning shift a short one, so that the boilers may be worked with equal intensity and vigour during the entire period of maximum load. The second shift in such a case would take the tail end of the load, and more or less "stand by" in the afternoon.

Firemen at collieries always work in shifts, because this fits in with the whole system. The morning is generally devoted to drawing coal, and is therefore the heaviest shift of the three. It lasts from 6 a.m. till 2 p.m. The afternoon shift is from 2 p.m. till 10 p.m., and is devoted to drawing any remaining coal, sending down supplies of pit props and stores in general, in addition to running the large pumping engines. The night shift from 10 p.m. till 6 a.m. is generally coal cutting and hauling the tubs in the pit. The air compressor, haulage engine, and, of course, the ever-running ventilation fan, make up the load, which is the second heaviest. This

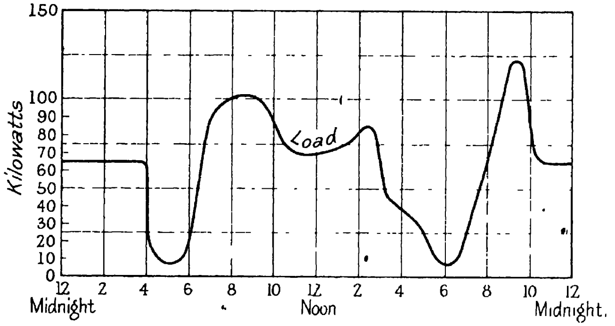

FIG. 127.—FACTORY LOAD FOR A DAY IN JUNE.

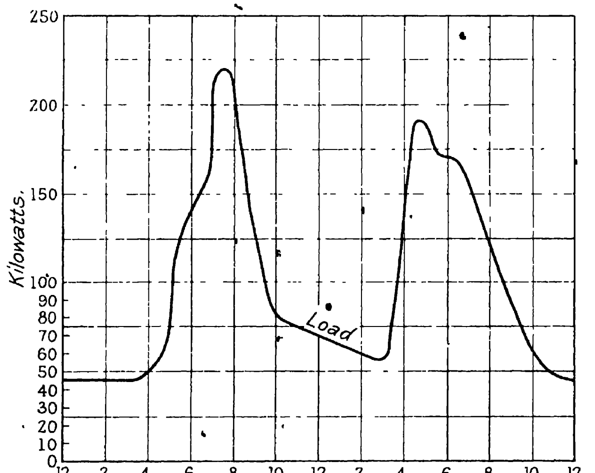

FIG. 128.—FACTORY LOAD FOR A DAY IN DECEMBER.

routine is not universal in collieries, but it will serve to indicate the conditions to which an engineer-chemist must adapt himself in the mining industry.

Electric power stations present yet another problem, but as the boilers in modern stations are generally fired by mechanical stokers the case is somewhat simplified. The load may be steady if the station supplies electrical energy to a manufacturing area, in which case it will be a day load with variations at mealtimes. If the station serves a business centre or residential area with electric light, the engineer-chemist must be ready for the emergency of a 400 per cent. or more increase in load in a few minutes, due to sudden fog, prolonged rainstorm, or other disturbance.

Whatever the requirements, the engineer-chemist must give them most thorough study before arranging the routine of his department. Under no circumstances must he issue a long list of instructions, drawn up in a haphazard fashion, and requiring to be altered a short time afterwards. Such a procedure simply gives the men the impression that he is not sure of his work, and produces a lack of confidence in his leadership, which is fatal. A carefully arranged time-table specially suited to the particular requirements of the works, with small modifications when they are obviously needed to meet some new conditions, will produce good results.

A feature of the time-table must be great flexibility. This is especially necessary when several boilers of different pressure are at work on the same plant.

Preparing a definite routine for the part of his staff which is not engaged on boiler-room tasks will be comparatively easy. The laboratory staff, for instance, may devote the morning to testing the fuel and water supplies of the previous day, leaving the afternoon free for other work such as testing the quality of consumable stores or undertaking other research work. The remainder of the staff will be engaged on fuel handling, ash removal, attending to pumps, and other miscellaneous duties. The store and records office, as well as the repair shop, will work according to a fixed programme, which will be discussed later.

Although the engineer-chemist must work the boiler house and everything in connection with it as a separate productive department, quite independent of the rest of the factory, he must, of course, keep in close touch with the requirements of the factory and co-operate with the other officials in every manner possible, so that the general efficiency of the factory may be increased.

(*b*) *Special Time-Table.*—A few examples of the various types of load which the engineer-chemist may be called upon to meet have been described, and it has also been said that the fixed time-table he will draw up to suit the particular requirements of the case must be sufficiently flexible to meet special occasions. Such special occasions arise when a boiler that has been cleaned is again put in operation, or one that is due for cleaning is "taken off." Or some special process work may have to be undertaken in the factory, for which an extra supply of steam is required. Whatever the special occasion may be, he must be ready for it and in a position to maintain the steam pressure. Very sudden heavy loads in electric power stations are experienced from other causes than those already described. For example, partial failure of a power station may occur during the peak load, and a neighbouring station may be asked to take over part of the load in addition to its own.

The engineer-chemist will be considerably helped in preparing a fixed time-table which is capable of being readily converted into a special time-table, by making an absolutely thorough examination of the steam-pipe system. In old establishments the pipe system is generally very complicated and little understood even by old employees. A careful study, however, may reveal possibilities of great flexibility in the arrangement. One or more boilers may be able to supply steam direct to certain departments in the event of special need, and a simple manipulation of the correct valves may enable the whole factory to " carry on " comfortably under conditions of unusual stress.

On board ship all the important ranges are in duplicate, according to Board of Trade and underwriters' requirements. These apply to the main steam-pipe range, the auxiliary steam-pipe system, and the feed water pipe layout, except that, in the last case, in addition to a main range and a donkey range, as it is called, each of the pipe systems can discharge to, and be supplied by, several ranges of pipes which interconnect. No such rules are in force on shore, although they are very necessary, but in many cases a system of pipes which has been built up over a period of years can, with a little scheming and alteration, be adapted in readiness for possible emergencies.

Too much reliance is frequently placed on the fact that the plant has worked in a certain manner for years, and the assumption is made that it will very kindly continue to do so. On no account must the engineer chemist possess a nature which " hopes for the best," and therefore tempts him to take risks or allow matters to slide. Such an attitude is absolutely fatal when dealing with steam-raising plant. A firm determination to have everything right and to see things through to the bitter end is the only policy that will bring success. The engineer-chemist must always remember that he is not there to *put things right when they have gone wrong, but to prevent them from going wrong.*

It is the rule rather than the exception to find a plant which is " undermanaged," and therefore engaged in one long struggle for steam. This condition may be, to a large extent, explained by lack of proper supervision when boilers are installed, but the situation is made worse by an almost entire absence of scientific control. Firemen are left " on their own," whether they really know their job or only pretend to, and such repairs and cleaning as may be necessary are undertaken when conditions have become so bad that a complete stoppage is necessary.

By instituting some system of scientific control and making a few minor structural alterations to the layout, most of the boiler plants in Great Britain could be worked with comparative ease to supply the necessary steam, and leave sufficient margin for reserve power to allow a boiler at a time to be " laid off " for cleaning. When once properly organized, a power plant can always be kept at maximum working efficiency, but when cleaning and repairs are only undertaken at certain times of the year, during the recognized holidays, it is practically impossible to obtain a uniform efficiency throughout the year.

(*c*) *Emergency Time-Table.*—It has already been pointed out that the fixed time-table should be of such a nature that it may easily be converted into a special time-table in the event of some special demand arising. In exactly the same way it must be possible to adapt the special time-table to emergency requirements.

Emergency requirements are those for which no preparations can be made beforehand, but a definite plan of action may be worked out to facilitate the speedy and efficient conduct of whatever operations may be necessary to meet a crisis.

A broken gauge glass presents no special difficulty unless a water-tube boiler is being forced, but in that event it will be advisable to call for assistance in order that the replacement may be effected with the greatest possible speed. Sometimes an obstacle presents itself, such as packing which has become very hard and refuses to come out, or a glass broken off very low in the bottom nut and hard to get hold of, and special precautions must then be taken. These, however, will only consist in opening the feed check to its fullest extent and easing down the fires, so that the boiler pressure may drop slightly and the feed pump accordingly supply this boiler in preference to any other at a higher pressure. If the boiler is fitted with a set of try cocks (compulsory in the case of marine boilers), these will give a fairly correct indication of the water level.

Fusible plugs are fitted in the crown of Lancashire boiler furnaces over the back end of the grate. If one of these melts, the water in the boiler is forced out under steam pressure, and extinguishes the fire. In such a case the feed check valve should be opened full to make up for the loss of water in the boiler, the fire should be speedily withdrawn, and the check valve should then be shut to avoid wasting feed water. The duration of the repair work depends on the temperature under which it has to be effected and the obstinacy of the job.

In the case of a tube burning out in a water-tube boiler or of a collapse of fire-brick arches, the forced and induced draught fans must be stopped, the fire must be immediately regulated to a minimum, or extinguished in the case of a fallen arch. Where a tube has burnt out, a constant supply of water must be admitted to the boiler until the fire has either been extinguished by the escaping water or withdrawn altogether. The fans must be stopped immediately the check valve has received attention. As soon as possible the check valve must be shut to avoid flooding the ash hoppers. If mechanical stokers are installed, the fuel supply will be shut off, and the grate advanced to maximum speed, so that the remaining fuel may be carried over the back dumping bars. A steady current of cold air should be allowed to enter through the fan inlet. This, although not good for the boiler, will at least absorb some of the latent heat in the brickwork, and minimize further damage to the steel structure.

Only the very commonest occurrences have been cited as illustrations. The number of mishaps from which a boiler plant may suffer is, of course, legion, and the compilation of a catalogue of them for the present work is out of the question. In all cases as soon as measures have been taken to prevent any further damage, the engineer-chemist must make arrangements to replace the injured steaming unit as far as possible. This may be done by increasing the load on the other boilers beyond what is advisable for continual working, or the most important departments only may be supplied, minor demands being refused until repairs have been effected.

The former course is practicable only if the engineer-chemist keeps his plant in first-class condition, the latter is dependent on the layout of the steam-pipe arrangement. This is, however, a suitable point at which to emphasize once more that every engineer chemist must be thoroughly familiar with his plant down to the smallest detail, so that when the occasion arises he may give his instructions quickly, yet without any sign of panic. Such decisive action will command the respect of all employees, and he can be sure that his instructions will be carried out by the men to the best of their ability.

Some accidents cannot be foreseen, but these are really very few. By far the greater number of stoppages are due to some failure which periodical inspection and a little common-sense would have prevented. Efficient operation, however, cannot be secured without a considerable expenditure of time and money, which a very large number of plant-power owners have yet to learn is true economy. Nobody advocates unnecessary work, but work which contributes to the efficient performance of a power plant and ensures the safety of many lives in its vicinity is not unnecessary, although it may be undertaken at a time when some men would be inclined to "put it off a little longer."

(*d*) *Hours of Working.* A brief indication how the hours vary in different industries has already been given, and the boiler-house staff must be worked accordingly. There are, however, special items to be watched, and one of the most important is in connection with hand-fired boilers. In an ordinary factory the engineer-chemist will know when to expect extra heavy loads, and must arrange matters so that the boilers will start with maximum pressure and have nice bright fires on the grates. If this matter is left to the firemen, without proper supervision, they will very probably commence cleaning fires too late, so that not only will the pressure be low just when steam is needed, but the fires will not have recovered sufficiently to consume large quantities of fuel with any rapidity. It is possible, also, to make the mistake of cleaning fires too soon, in which case they will have become dirty again when the critical period arrives. Sometimes, again, it is very difficult to arrange the cleaning of fires so as to suit the requirements of the factory, and to avoid clashing with the change of shifts, or with meal hours.

Factories generally work recognized hours during the daytime, and the boiler-house staff, firemen, ash wheelers, trimmers, and pumpmen will work right through, observing the same meal hours as the remaining employees. If the work is very heavy the firemen may work in two shifts of equal length, or the division may be made as already explained on p. 147, the morning and afternoon shifts changing about alterntate weeks. If the men are on fixed weekly pay this will be a matter of secondary importance.

It should always be remembered that even boilers fitted with mechanical stokers require firemen to regulate the mechanical stoker, to shovel back riddlings, and to give a little personal attention to the front part of the grate by judiciously applying a rake. Working in shifts is the easiest system, because no account is taken of meals or other breaks, and the first duty of the new shift is to clean fires and give the boilers such attention as will ensure their satisfactory working during the remainder of the shift. In some cases only day and night shifts are run, but these cases are few and of no great importance. The average factory has one fireman on night shift, or in small plants the night watchman is expected to include the boiler house in his round. This latter practice involves considerable risk. If the night watchman knows something about boilers there may be little objection, but generally he does not possess this knowledge. Numerous accidents have resulted from his incompetence to deal with even small matters, although for this he is hardly to blame, being a watchman and not a boiler attendant.

In boiler plants which are worked in shifts, such as collieries, the duration of each shift is eight hours, and the men change about from one week to the other. The class of men on each shift will depend on the load, and the requirements of the plant to which the steam is supplied. If the load is heavy there will be no difference between the shifts, but if the duties are light certain boilers only will be worked at full power, and the others " banked down." This is more economical than working all the boilers at reduced output. The number of men required will vary accordingly.

In most cases only the firemen, ash wheelers, and pump men will be on shift, and the remainder of the boiler department staff, such as the technical staff, workshop staff, and members of the store and records office, together with other miscellaneous labour, will be day workers.

(*e*) *Duties*.—So far, the executive control of the boiler-house staff has been considered, but nothing has been said about the types of men employed or their duties.

The duties of the firemen are to work the boilers according to the instructions of the engineer-chemist in such a manner that the pressure remains constant, and, if superheaters are fitted, the temperature also. In order to work efficiently all the men on duty must obey the orders of a senior, who is generally the leading fireman, although in some cases it is the pump attendant, especially if the latter be a recognized mechanic. Assuming the leading fireman to be in charge, he will give his orders according to the instructions of the engineer-chemist, and such orders will chiefly be in connection with the boiler house itself. He is responsible for the routine in which the boilers are fired, and also the order in which the furnaces are cleaned. He must say when cleaning fires is to commence, in order to prevent two boilers being under treatment at the same time. This last is very important, because most firemen like to rush the somewhat unpleasant task, and it is a common sight when going into a firehole to find several firemen all cleaning out fires and the steam pressure falling steadily.

The leading fireman must see that the fires are cleaned out in a proper manner, and not according to the firemen's own fancy. If the men will not obey the leading fireman, the engineer-chemist must spend a week in the firehole and find out what is wrong. A little tact generally goes much further than a lot of bullying, but there are some extreme types who cannot be handled, and they had better find employment elsewhere. Generally it is simply a case of ignorance, for which the person in charge is to blame. Once an engineer-chemist has made sure that every fireman understands the method he wishes adopted there should not be much trouble.

It is important that a fireman should know why he is doing a certain duty in a particular manner, because, if he understands the logic of it, he will work according to his instructions, but if he does not see why the method is better than his own he will do the job in his own way when left alone. The reason for this is not always laziness or stubbornness; but he considers he has a right to know something about his job, and instruction camouflaged as a little friendly advice will do more good than "orders barked out with suitable dressing." If a man really does not care, and cannot be induced to follow instructions, there is no place for him in the plant.

The leading fireman will read the automatic fuel weighing machine once or twice a day, according to the engineer-chemist's wishes, but he must be told that it is very important to take the reading at the same time every day or to note the exact time at which he takes it. In the ordinary boiler house the fuel will be weighed and the bunkers levelled off once or twice a week. The leading fireman will see that the bunkers are ready at the same time every week, when the engineer-chemist will himself take the height of the fuel in the bunkers.

Further, the leading fireman will be responsible for the fuel samples, and as this is a responsible job the engineer-chemist may detail a junior chemist to take the samples until the fireman understands how it is done. A fairly large sampling box must be kept in the firehole or boiler house, but so placed that it does not inconvenience anybody. At regular intervals during the day—the oftener the better, although on a plant where the same fuel is burnt from month to month and where a test is made every day, four times may be sufficient—the fireman will take a shovelful of coal at random from that supplied to each boiler. In other words, if there are four boilers, he will put sixteen shovelfuls of coal into the sampling box. At the end of each day this box is emptied, and the fuel spread evenly over the floor and broken into small pieces. The fuel is then thoroughly mixed and again spread out and "quartered" into four equal parts by making a cross, two lines at right angles. The coal in two opposite quarters is thrown back into the bunkers, and the remaining quarters thoroughly mixed, further broken up, and, when the coal has again been spread out, quartered once more. The coal in two opposite quarters is returned to the bunkers, and the remaining quarters are further pounded. In this manner a very small quantity of very finely powdered fuel will be obtained, and this should, if the sampling has been done correctly, represent a true average mixture of the fuel burnt that day.

A much simpler method is to put the fuel straight through a Sturtevant patent coal-crusher and sampling machine.

This machine is illustrated in fig. 129, which shows an outside view with the door open, and fig. 130, which is a sectional view. It not only reduces the coal to a fine powder, but the degree of fineness can be regulated, and it is so designed that a small percentage is discharged through a separate pipe. An accurate sample may thus be obtained in a fraction of the time taken in quartering the coal.

The fuel sampling is of the greatest importance. A sample of coal taken from one bunker by filling a tin with a shovel is useless and need not be analyzed. Where mechanical stokers are installed, the fuel falls from overhead shoots into the hopper in front of the boiler. The larger pieces of coal, due to the angle of repose of the fuel, fall towards the corners of the hopper. In order to obtain a correct shovelful for the box a fireman must insert his shovel well under the shoot, and not simply take practically "pure fuel" out of the corners of the hopper because it is the easier to reach.

The number of coal samples will vary with the fluctuation in the quality supplied, and the engineer-chemist will use his discretion in the matter; but in cases where the supply is extremely constant, the number might be cut down to four a week on a small plant—on the distinct understanding that the box in the boiler house really contains a true selection of fuel for the period, and is not filled on the last day for appearance's sake.

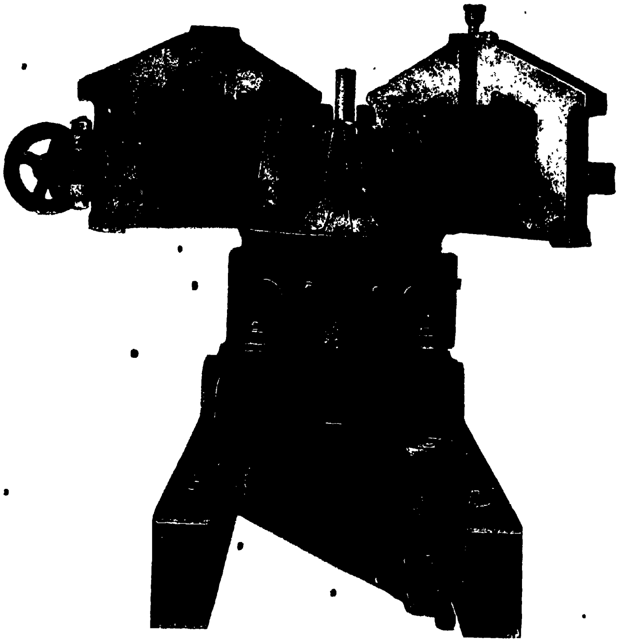

FIG. 129.—STURTEVANT COAL CRUSHER. OUTSIDE VIEW WITH DOOR OPEN.

The ash wheelers will take their orders from the leading fireman, and should be trained to work together with the firemen when cleaning fires. Cleaning the fires of boilers must be performed as quickly as possible, whether they are hand-fired or mechanically-fired. With mechanically-fired Lancashire boilers the ashes only have to be raked out of the lower half of the flue, in order to replace the steaming unit as soon as possible. The ash wheeler will hand the fireman his tools, stand ready with the ash-cooling hose, see that plenty of small fuel is handy for rekindling the fire, and assist with the dampers. These men far too often take the attitude that they are ash wheelers and nothing else.

In boiler houses which have a reclamation plant the ash wheeler can be paid a small bonus on the weight of coke he saves. This will give him a personal interest in the working of the reclamation plant which is under his care. If the total bonus becomes very high it is almost certain that the ash wheelers are in league with the firemen, and that the latter are not cleaning the fires as they should An inspection by the engineer-chemist to find out what is going on, and a reminder to the culprit that his services may soon be no longer required, will put a stop to any tricks of that description. On the other hand, if the ash wheeler adds a shovelful or so of separated clinker to the pure coke to increase the weight of his "saving" the firemen will soon complain about the machine not working properly In any case, the engineer-chemist should inspect the boiler-house refuse and the reclamation plant at least twice a day. One of the ash wheelers will take a representative sample of the boiler-house refuse much as the fuel sample is taken, although a lower standard of accuracy will suffice, the analysis only serving to show how much unburnt fuel the refuse contains.

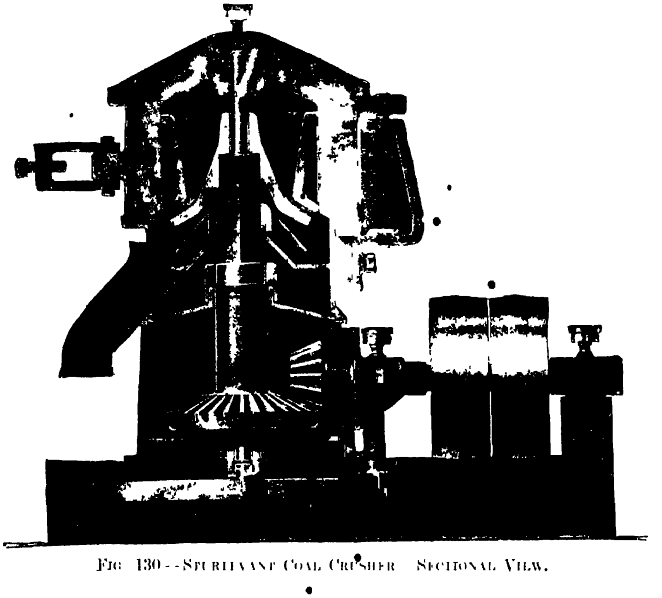

FIG 130.--STURTEVANT COAL CRUSHER SECTIONAL VIEW.

Pumpmen are attached only to the larger boiler plants, as in the smaller plants the leading fireman is responsible for the supply of feed water. In plants that have a pumpman it will be his duty to attend to the pumps, water-softening plant, feed-water heating apparatus, de-oiling plant, economizers, filtering appliances, and any other arrangements for the separation of organic matter. The work is more or less in the form of periodical inspection, and needs no further comment.

If the pump attendant is senior to the fireman he will supervise the blowing down of the boilers. In any case, a responsible person must be present when this daily operation is performed, for it involves a greater risk than is generally admitted.

The pumpman will also be responsible for a daily sample both of the untreated water and of the softened water supplied to the boilers. If any condensed steam is de-oiled before being mixed with the softened water it will be advisable to include a sample of de-oiled condensate. The samples should be taken by allowing a Winchester bottle, having a capacity of about a quart, to fill drop by drop.

The raw fuel, except in the case of powdered fuel plants, should not require treatment or much handling, and in any case this will be done by unskilled labour, supervision only being required from the boiler-house staff.

CHAPTER XIII

OFFICE STAFF

(*a*) *Technical Chemists.*—In addition to the boiler-house staff, the engineer-chemist will be responsible for the office staff of his department, which comprises the technical chemists attached to the laboratory, the technical storekeeper in charge of the stores, and the records office with which the latter will be closely associated.

The laboratory staff will, under the supervision of the engineer-chemist, be responsible for all measuring instruments, except the water and fuel measuring apparatus which must be attended to by a skilled fitter who has the necessary engineering tools for this comparatively heavy work. It will be part of the daily routine of the laboratory staff to analyze all the fuel, ash, and water samples. The samples from the previous day should be brought into the laboratory every morning, together with the form shown in Table III. When the results have been entered on this sheet it should be returned to the records department for compiling statistics and filing.

So also the leading fireman will hand in his sheet, as shown in Table IV., giving the figures for total fuel burnt, if recorded daily, and the water evaporated as shown by the meter, together with any other records that may be required of him.

The number of readings taken per day, and the persons by whom they are taken, will be determined by the engineer-chemist, whose instructions will be influenced by such considerations as the size of the plant and number of self-recording instruments provided.

In the opening chapter it was stated that boiler plants vary enormously in character. Power units differ widely in size and method of installation, and with their auxiliary appliances and subsidiary plant are capable of an almost unlimited diversity of arrangement. The scheme given in the specimen tables for recording the performance of a boiler plant embodies the essential principles on which all good practice is based, but the forms will require modification in detail to meet the special circumstances of particular plants.

A chemist will go round the plant every morning and attend to the recording apparatus, placing new charts on the instruments, replenishing the supply of ink, and inspecting the mechanism for defects. The used charts will be handed in at the records office for examination, and filing after they have been dated, etc. Every afternoon the engineer-chemist will inspect all the records, analysis results, and data sheets of the previous day. Any abnormal increase in fuel consumption or decrease in steam-supply or other phenomena requiring explanation must immediately be

TABLE III

SAMPLE SHEET

Date..................

Name and description of fuel..
Received from..
Remarks..
Weight of fuel received..
Fuel in bunkers..
Weight of fuel burnt (by calculation, Lea meter, or weighing)...................
Weight of boiler refuse..
Estimated weight of unburnt fuel in refuse (based on samples)..................

FUEL SAMPLES.

Description of fuel ....
Reference No. ....

ASH SAMPLES.

Sample taken from boilers Nos.....................
Reference No. ....

FEED-WATER SAMPLES.

Before treatment .... Reference No.........
After treatment .... Reference No.........

Note.—All samples must be labelled for identification purposes.

LABORATORY ANALYSIS.

Fuel........................ Sample No. ....
Calorific value ....
Moisture....................
Ash content ....
Ash .... Sample No. ....
Calorific value ....
Percentage unburnt coke......

Feed water..........Turbidity ....
Sample No. ..... Before treatment........... Temporary hardness......
Permanent hardness ......
Sample No. ..... After treatment............ Temporary hardness......
Permanent hardness ......

GENERAL REMARKS.

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investigated, and the investigation be continued until the engineer-chemist is satisfied that he knows exactly what has happened, and why? The efficiency of a plant can only be maintained by personal investigation of the smallest details and a rigid adherence to methods of scientific control.

TABLE IV

Boiler-House Log Sheet

Date . . .

Name of plant . . . .
Load conditions . . . . . .
Numbers of boilers in use
Total fuel used in tons
Total water evaporated in gallons
Temperature of feed water at meter . . . .
Temperature of feed water before economizer . . . .
Temperature of feed water after economizer . .
Boiler draught . . . .
Economizer draught . . . . . .
Chimney draught . . . . . .
Carbon dioxide recorded . . . .
Smoke . . . .
Temperature of gases before economizer . . . . .
Temperature of gases after economizer . . . .
Steam pressure of high-pressure boilers . . . .
Steam pressure of low-pressure boilers . . . .
Numbers of superheaters working . . . .
Temperature of superheated steam . . . .
Percentage steam used by auxiliary machinery . . . .
Total grate area in use . . . .

Deductions.

Fuel burnt per square foot of grate area in pounds per hour . . . .
Water evaporated per pound of fuel burnt . . . .
Water evaporated per pound of fuel burnt from and at 212° F. . . . .
Efficiency, Gross . . . .
    Nett working . . . .
    Boilers only . . . .
    Economizer only . . . .
    Superheater only . . . .

Scientific control must be applied to the examination of every substance used in connection with the steam-raising plant, among which may be mentioned the ingredients for the water softening plant (lime, soda ash, alumina, etc.).[1] Although the laboratory staff will probably not be able to spare the time necessary for a detailed quantitative analysis, each of these ingredients can be subjected to simple tests for the purpose of ascertaining their general quality and their fitness for the uses for which they have been purchased. Commercial soda, for instance, often contains an undue quantity of water. No manufacturer wishes to be charged for water at the price of soda, and it is the engineer-chemist's business to see that his department is not debited with the cost of material which contains a large percentage of useless matter.

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[1] *Engineering Chemistry*, H. J. Phillips.

Economy consists not only in doing without what is unnecessary, but in the art of using that which is necessary in the most efficient manner.

Only the best mineral oil having a very high flash point must be used for lubricating purposes in plants which are fitted with superheaters, and although the large oil companies themselves employ a large staff of skilled chemists, and generally guarantee a certain standard of purity, the quality of the oil should, nevertheless, be tested. The oil usually arrives in large wooden barrels without any special distinguishing mark, and the ordinary method of fastening is to nail a piece of tin over the wooden bung, so that there is ample scope for dishonest persons of an inventive turn of mind.

The properties of special firebricks, quality of paint and consumable stores, nature of pipe-insulating material, composition of scale, specimens of corrosion, samples of sediment, provide further subjects for investigation.

Physical experiments and investigations into the radiation of heat and condensation of steam will also form part of the technical chemist's duties.[1]

Excellent books are already available dealing with most of the scientific instruments used in steam-raising plants, and the better known manufacturers have themselves issued publications which would be a valuable addition to any library.

The analysis of fuels is purely a chemist's job.[2] A very rough summary of the proceeding will be given later in the chapter, together with an alternative method of test which may be adopted where a proper laboratory is not available.

Most factory owners do not realize the value of instruments, because they do not see how a saving can be effected by installing them. Decorating the walls of a boiler house with expensive pieces of apparatus will never save one halfpenny worth of fuel, but the brains which interpret their meaning and apply the information thus gained to improve the boiler plant efficiency may effect very large economies. This work is, in fact, the most responsible the engineer-chemist has to undertake.

Very wonderful apparatus is now made, which *records* all the information necessary. Wherever possible, factory owners should pay the extra cost and install recording, as distinct from indicating, instruments. Indicating instruments must be read, and are useful for a boiler test when a trained staff is at work, but recording instruments are preferable for everyday working. A list of the instruments necessary for accurate record-keeping will include a pressure gauge, draught gauges, pyrometers, carbon dioxide recorder, Orsat apparatus for gas sampling, thermometers, steam meter, and apparatus for ascertaining the weight of water and fuel consumed. The instruments can, with advantage, be placed in a special dust-proof house fitted with a small bench at which charts can be dated and repair work executed. The installation may vary from a carbon dioxide indicator to a complete battery of recorders.[1]

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[1] *Trans. Royal Society*, 1897.

[2] *Fuels, Solid, Liquid, and Gaseous* H. J. Phillips.

(*b*) *Technical Storekeeper.*—In most boiler plants all supplies are handled by the general store, and where the plant is small this is quite permissible, provided that separate account books are kept. With larger plants it is advisable to run a separate store, or at least to combine only the boiler department and the repair shop for store purposes.

Unless the cost of all stores used by the boiler department, consumable and unconsumable, can be readily ascertained, the cost of producing a unit of steam cannot be accurately computed. It is of little use, for example, to prepare detailed figures of the cost of softening the water if separate accounts are not kept of the oil supplied respectively to the boiler department and the power house Unless *all* the details required for correct accounting are available, little value attaches to those which can be used.

The boiler house often " borrows " waste for cleaning purposes, etc., in which case someone makes a rough guess at the quantity supplied—generally to the disadvantage of the boiler department. There is no need for such happy-go-lucky methods. If three bales are ordered, let one go to the boiler-house store, and one-third of the bill be charged to the boiler department.

The storekeeper should collaborate with the laboratory, and submit samples of any consumable stores purchased so that these may be tested and advice given as to their quality. A collection of trade information, including a properly indexed record of all literature received and of all visits paid by commercial representatives, is a valuable asset to any boiler-house record office.

The storekeeper will also keep a record of all non-consumable stores, so that repair costs may be accurately computed and— what is more important--the products of one firm compared with those of another as regards durability, maintenance cost, etc. On account of the great similarity of the work undertaken by the technical storekeeper's department and the records office the latter will be under the supervision of the storekeeper, and will practically form part of the store organization, although separate ledgers must be kept.

(*c*) *Records Office.*—The records office is responsible for accurate records of everything supplied to the boiler department and the use to which it has been put, and of any commodities that have been supplied by the boiler department to other departments.[2] The office will also record the power, water, steam, etc., supplied to the different departments and outside the works. The fuel account will be kept separately, and in a similar manner to a ledger, fuel received being entered on the left-hand side, and fuel consumed on the right. When the returns for the fuel in hand are received, they should, when added to fuel burnt, balance with the left-hand side.

A separate account should also be kept of the reserve fuel supply, and any fuel transferred from reserve should pass through the ordinary fuel account in exactly the same way as fuel received from any other source. Fuel so transferred will, of course, be entered on the right-hand side of the reserve fuel account.

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[1] *Gas Works Recorders*, Dr. L. A. Levy.

[2] *Factory Administration and Costs Accounts*, E. T Elbourne.

The records office will [illegible]ll the tickets taken with the weighbridge stamping device, in order to check [illegible]t received with that stated on the invoice. Where boiler-house refuse is s[illegible]side merchants or made into bricks which may either be sold or used by [illegible], the value of such products must be entered in the books, so that the depart[illegible]y be credited with the sum received from their sale or with the equivalent of their market price if they are retained for the firm's use.

The water account may be kept in a similar manner to the fuel account, but the left-hand side will show the quantity of water softened (or purchased if town supply is used), and on the right-hand side will be entered the quantities supplied to boilers and other departments. If no department other than the boiler plant is supplied with softened water, the difference between the total quantity of water consumed by the firm and that recorded by the boiler-house meter represents the consumption of untreated water in other departments. Even though the quantity of water used by the other part of a works is small and confined to sanitary requirements, the boiler house should not be debited with its cost. If the amount of softened water used by the boiler department is small compared with the consumption of the rest of the factory, careful records must be kept. The hosiery finishing trade is a case in point. The pump mechanic usually looks after the softener because it is considered to be his duty, although most of the water finds its way into the boiling vessels, and the difference between the quantity of water softened and that consumed by the boilers is so large that disputes constantly occur. The factory will never admit any waste which cannot be proved by properly kept records.

Accurate records should be kept of all electrical energy supplied to the department whether from outside or from the factory power house, because it is only by taking such items into account that the actual cost of production can be ascertained and comparisons made.

The power analysis will show the exact performance of the boiler plant, and if steam meters are installed it will be possible to record the exact amount of steam supplied to each department, although this is of more interest to the departmental manager than the engineer-chemist. Should a dispute arise over the fuel consumed, as in the case of an increase compared with the previous month, due to extra demands for steam, the records will show that more steam has been supplied, and that the increase in fuel consumed is not due to a decrease in the efficiency of the boiler department. This may be very useful, as the impossibility of generating steam without consuming fuel is a fact often overlooked in those industries where large quantities of steam are used for boiling.[1]

The data supplied by the technical storekeeper, added to the cost of fuel and other items, such as wages, depreciation, interest on capital, etc., will make it easy to calculate the total cost of producing a unit of steam. Fig. 131 shows how these items may be represented graphically.

As far as possible records must be kept of the steam consumed by all the auxiliaries

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[1] "Power and Heat Costs in Chemical Works," *Trans. Chem Ind*, 1913.

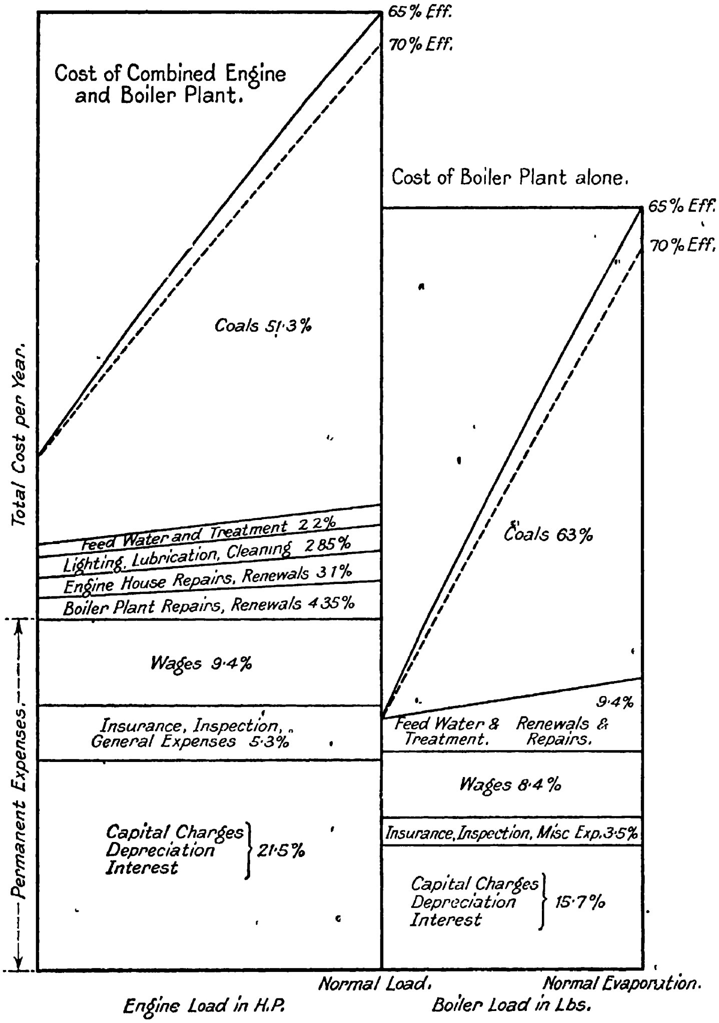

FIG. 131.—COST OF POWER PRODUCTION.

connected with the boiler plant, such as pumps, fan and economizer engine, steam jets, etc. Table V. is a suggestion for a scheme for tabulating costs, and indicates how the various items can be arranged.

TABLE V

BOILER DEPARTMENT ACCOUNT

Date..................

Name of plant..

EXTRACT FROM BOILER-HOUSE LOG.

1. Number of boilers at work..
2. Total number of hours boilers have been steaming......................
3. Total heating surface (square feet)..................................
4. Total grate surface (square feet)....................................
5. Steam pressure (pounds per square inch)..............................
6. Temperature of steam (degrees Fahrenheit)............................
7. Calorific value of fuel (B.T.U.).....................................
8. Ash content of fuel (per cent.)......................................
9. Moisture (per cent.)..
10. Total water evaporated in pounds.....................................
11. Total fuel consumed in tons..
12. Pounds of water evaporated per pound of fuel.........................
13. Feed-water temperature, before heating...............................
14. Feed-water temperature, after heating................................
15. Flue-gas temperature at chimney......................................
16. Efficiency of boilers (per cent.)....................................
17. Efficiency of superheaters (per cent.)...............................
18. Efficiency of economizers (per cent.)................................
19. Gross efficiency of plant..
20. Steam used by auxiliaries..
21. Nett efficiency of plant...

EVAPORATION COSTS.

22. Price of fuel per ton..
23. Tons of fuel burnt...
24. Total cost of fuel...
25. Weight of ashes..
26. Cost of removal per ton..
27. Total cost of removal..
28. Combined cost of fuel..
29. Price of water per unit..
30. Cost of materials for purification...................................
31. Price of purified water per unit.....................................
32. Cost of water evaporated...
33. Evaporation cost of a unit of steam..................................

TABLE V—*Continued.*

WAGES.

34. Firemen
35. Ash wheelers
36. Pump attendants
37. Bricklayers
38. Fitters
39. Pipe coverer
40. Unskilled labour
41. Wages cost of a unit of steam

MAINTENANCE CHARGES.

42. Boiler cleaning
43. Flue cleaning
44. Cleaning feed-water purification plant
45. Special maintenance costs (emergency measures, etc.)
46. Supervision
47. Laboratory and records office
48. Maintenance cost of a unit of steam

CONSUMABLE STORES AND POWER.

49. Cost of lubricants
50. „ firebricks
51. „ building materials
52. „ packing, gauge glasses, etc.
53. „ firing implements
54. „ engineering stores
55. „ renewals
56. „ electric power
57. „ electric light
58. Stores and power cost of a unit of steam

REPAIR COSTS.

59. Repairs to boilers
60. „ superheaters
61. „ economizers
62. „ pumps, injectors, and meters
63. „ instruments
64. „ feed-water purification plant
65. „ fuel handling plant
66. „ ash handling plant
67. „ steam pipe system
68. „ water pipe system
69. „ flues and chimney
70. Repair cost of a unit of steam

TABLE V—*Continued.*

General Costs.

71. Special testing charges ....
72. Boiler inspection ....
73. Fire insurance..........
74. Special insurance (accidents, etc.)..........
75. Repair to buildings ....
76. Special charges..........
77. General cost of a unit of steam..........

Overhead Costs.

78. Ground rent ....
79. Depreciation of plant..........
80. Interest on capital..........
81. Special local charges ....
82. Overhead cost of a unit of steam..........

Summary of Costs.	£	*s.*	*d.*
Cost of water and fuel per unit			
,, wages per unit			
,, maintenance per unit			
,, stores per unit			
,, general charges per unit			
,, overhead charges per unit			
Grand total	£		

(*d*) *Instruments.*—A simple form of draught gauge was illustrated in fig. 49. This instrument costs little, and should be fitted at the front of every Lancashire boiler.

Water-tube boilers require more sensitive instruments. Many of these boilers work on the balanced draught system, and the difference in level of the water in the gauge would be too small to read with accuracy on an ordinary gauge. A special instrument, fitted with a pointer recording over a small arc of a large circle, should therefore be used. Very small variations can then be clearly read at a considerable distance from the instrument.

A recording draught gauge may be installed to show the draught in the main flue, and when used on natural draught plants this will indicate when the flues should be cleaned.

A pyrometer is an instrument for measuring the temperature of the flue gases.[1] Several types are manufactured, but that in most general use is known as the thermo-electric pyrometer. Thermo-electric pyrometers consist essentially of a thermo-electric circuit in which the hot junction is exposed to the temperature to be measured, and the resulting electro-motive force is measured by a suitable recording instrument. If two wires made of dissimilar metals or alloys are joined together at their ends, and if one of the junctions is heated, an electro-motive force is set up which gives rise to a current in the circuit. The magnitude of the current and its direction depend upon the nature of the metals employed, and upon the temperatures of the "hot" and "cold" junctions respectively. If, therefore, a suitable galvanometer is introduced into the circuit, it is possible to determine the temperature of the hot junction from the deflection of the galvanometer.

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[1] *Pyrometry*, C. R. Darling.

Fig. 132 shows a thermo-junction, which consists of two wires of dissimilar metals or alloys generally iron and constantan (which is an alloy of 60 per cent. copper and 40 per cent. nickel)- fused together at one end and connected to the pyrometer at the other. These wires are threaded through double-drilled fireclay tubing, being thus insulated from one another throughout their length. The wires are enclosed in a covering of steel. The terminals of the thermo-junction are connected to those on the pyrometer (fig. 133), which is a very sensitive galvonometer.

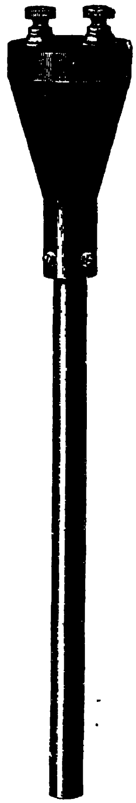

Fig 132.—Thermo-Junction

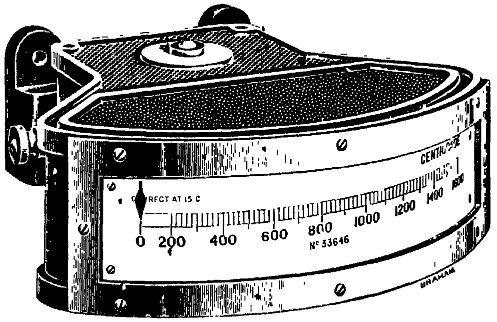

Fig. 133 Sarco Indicating Pyrometer

The current generated at the fused end, or junction, of the two wires is proportional to the heat at that point, which is recorded on the instruments directly, in degrees Centigrade or Fahrenheit, as may be provided for.

In the "Sarco" recorder a special pen and inking device take the place of the pointer used in the indicator. The pen is alternately inked and pressed down by clockwork on to a printed chart revolved by a separate clock movement. Thus a series of dots is produced, forming a practically continuous record of the temperature.

Carbon dioxide recorders are of three main types:

(1) Volumetric recorders, in which the carbon dioxide contained in a definite

volume of flue gases is absorbed chemically, and the consequent reduction in volume is recorded as a percentage.

(2) Diffusion recorders, in which the carbon dioxide is absorbed chemically after diffusion through a porous pot, thus producing a pressure difference between the interior and exterior of the porous pot. This pressure difference is recorded, and is a function of the amount of carbon dioxide.

(3) Electrical carbon dioxide recorders. In this instrument the variation in the electrical conductivity of the gaseous mixture, which is a function of the percentage of carbon dioxide, is recorded.

An example of a volumetric recorder is the "Sarco" carbon dioxide recorder shown in fig. 134.

The action of the apparatus will be made clear by reference to fig. 135. The power required to procure and deal with the gas samples is derived from a fine stream of water at a head of about two feet. The flow of water is regulated by a screw clip, and enters the instrument at (8) through the small glass nozzle (9). The water flows through tube (74) into the power vessel (82), compressing the air above the water level, and this pressure is transmitted to vessel (87) through tube (78). The pressure thus brought to bear on the surface of the liquid with which vessel (87) is filled (to mark 95) forces the liquid upwards through tubes (91) and (93). Thence it passes up into vessels (68), (67), (77), and (66), and into tubes (49), (51), and (52).

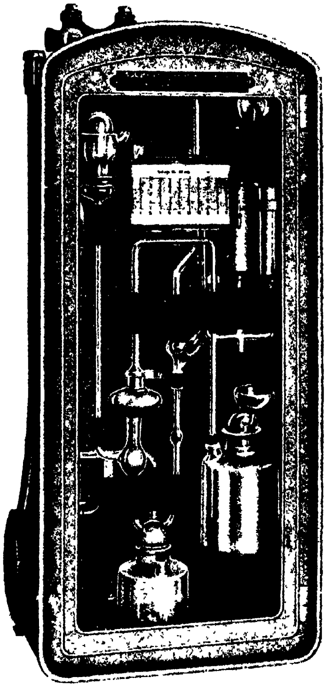

FIG. 134.—SARCO CARBON DIOXIDE RECORDER.

It rises until it reaches the zero mark (71), which will be found on the narrow neck of vessel (67). At the moment it reaches this mark the power water, which, simultaneously with rising in vessel (74), has also travelled upwards in syphon (72), will have reached the top of this syphon, which then commences to operate, and a much larger quantity of water is disposed of than flows in through the injector (9), so that the power vessels (74) and (82) are rapidly emptied again. As the pressure on vessel (87) is thus released, the liquids return from their respective tubes into this vessel. Assuming tube (49) to be in connection with a supply of flue gas a sample of this is drawn in from the continuous stream which passes through (43), (45), and (46), as the liquid recedes in (49), by the partial vacuum which is created by the falling of the liquid. As soon as the flow in the syphon stops, vessel (82) begins to fill again, and the liquids in tubes (91) and (93) rise afresh. The gas in (67) and (68) is now forced up into tube (50), and caused to bubble right through a solution of caustic potash (specific gravity 1·27) with which vessel (91) is filled to a point (64) marked on the outside. In this process any carbon dioxide that may be contained in the gas is quickly absorbed by the potash. The remaining portion of the sample collects in (62) and passes up through (60) into tubes (57) and (58). The gas now passes under the two floats (18) and (26), of which the former is larger and lighter, and will, therefore, be raised first. By turning the thumbscrews (14) and (15) the stroke of this float is adjusted until exactly 20 per cent. of the whole sample remains to raise float (26), when nothing is absorbed in (91), as would be the case if air were passed through the recorder. This float has attached to it pen (36), which is caused to travel downwards on the chart as the float rises. If no carbon dioxide were contained in the gas, nothing would be absorbed by the potash in (91), and the whole of the 20 per cent. would reach float (26) Thus the pen would travel the whole depth of the chart, from the 20 per cent. line at the top to the zero line at the bottom.

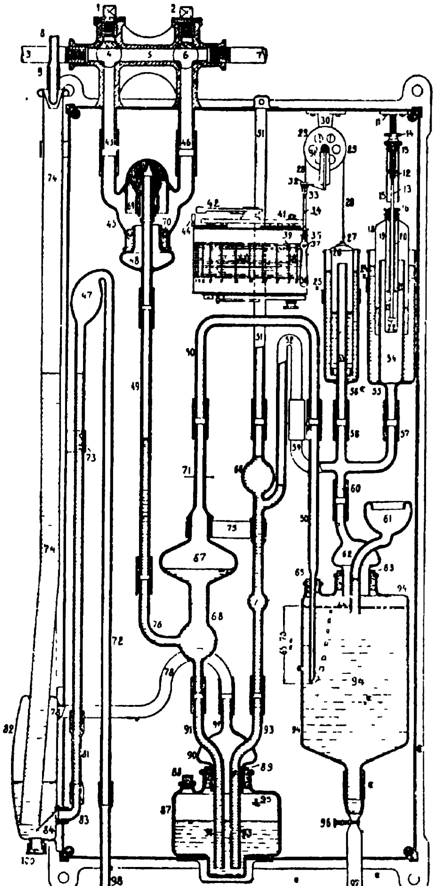

FIG 135—DIAGRAM OF THE SARCO CARBON DIOXIDE RECORDER

In actual working any carbon dioxide gas contained in the sample will be absorbed by the potash, a correspondingly less quantity will reach float (26), and pen (36) will not travel right down to the bottom of the chart, but will stop on the line which denotes the percentage of carbon dioxide in the sample. On the return flow of the liquid the gas is pushed out from under floats (18) and (26), through the tubes (57) and (58), and into tubes (59) and (52). From here it passes out into (66)—as soon as the liquid has fallen below the outlet of tube (52)—and through tube (51). The gas, when analyzed, leaves the recorder by a set of tubes entirely separate from those through which the samples are obtained, so that there is no possibility of mixing the old with the new.

An example of a diffusion apparatus is illustrated in fig. 136, which shows a W.R. carbon dioxide indicator.

The operation of the instrument is shown diagrammatically in fig. 137. The flue gas is drawn through the apparatus by the aspirator (S), which is connected to the chimney, and operated by the draught therein. The gas enters the instrument through a filter (F), and after being freed from suspended solid particles, it flows into a chamber containing a porous pot (P). Leaving this chamber the gas passes through a bottle (B) containing water, which serves as a tell-tale, so that the flow of gas through the apparatus is under observation, and any stoppage in the connecting pipes will be indicated by a partial or complete cessation of the flow of bubbles. The gas then passes through the cock (E), which serves to control its rate of flow to the aspirator (S).

The porous pot (P) contains an absorbent cartridge (R), filled with a material which rapidly absorbs carbon dioxide. As the gas flows over the pot (P) it diffuses into the interior, and the carbon dioxide which it contains is removed by the absorbent. A difference of pressure is thus set up between the interior and the exterior of the porous pot (P), and the amount of this difference will depend upon the volume of gas absorbed from the interior—that is, upon the percentage of carbon dioxide. The measurement of differential pressure is indicated in the diagrammatic sketch by a simple water gauge. In the indicator the pressure difference is recorded by a vertical column of water in a glass tube fixed to a graduated scale.

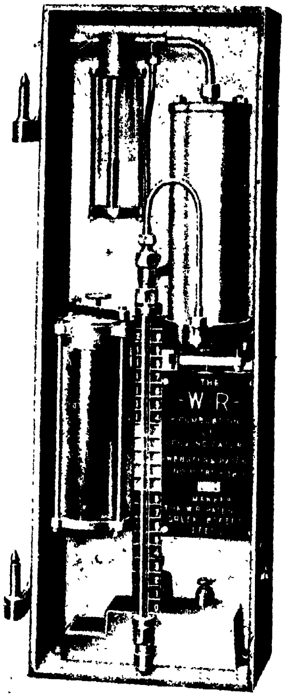

FIG. 136.—W.R. COMBUSTION INDICATOR.

Another example of the diffusion type of instrument is the "Econometer" carbon dioxide tester of Messrs. Kelvin, Bottomly, and Baird. The instrument is very small, self-contained, and designed to meet the requirements of those who must have a portable instrument to test the percentage of carbon dioxide in flue gases. A sample of gas is drawn into a cylinder by working a piston, and when the gas is in the cylinder the pressure is read on a manometer. The inlet and outlet connections to the cylinder are shut, and those to a chamber containing absorbent chemicals are opened. The gas is pumped through the absorbent several times, and the piston is finally depressed until the pressure in the manometer is the same as at the beginning of the test. When the sample is drawn into the cylinder and before the connections are changed over to the container with the absorbent, the piston must be at the top of its stroke, otherwise an incorrect reading will be taken on the manometer. The displacement of the piston, in order to show the same pressure on the manometer as at the commencement, is proportional to the carbon dioxide absorbed, and the proportion is read off on the graduated piston rod.

A further type of apparatus, which works on a different principle from those just mentioned, is the "Ranarex" carbon dioxide indicator. It is entirely mechanical in its action, and neither uses any chemicals nor embodies any delicate electrical or other devices. Its essential parts are two fans which are kept in rapid rotation by means of a small electric motor at the top of the instrument. The fans run at the same speed, each in its own chamber. In the chamber adjacent to each fan is a disc with vanes, so mounted that it tends to rotate owing to the friction of the air or gas set in motion by the vanes of the driven fan. The tendency to rotate is proportional to the density of the gas in the chamber, and this fact makes it possible to determine the percentage of carbon dioxide. The magnitude of the torque varies jointly with the density of the gas in the chamber and the square of the speed of the impeller. One chamber is filled with flue gas and the other with pure air, so that, as the speed of the impellers is the same, the torques transmitted to the recording

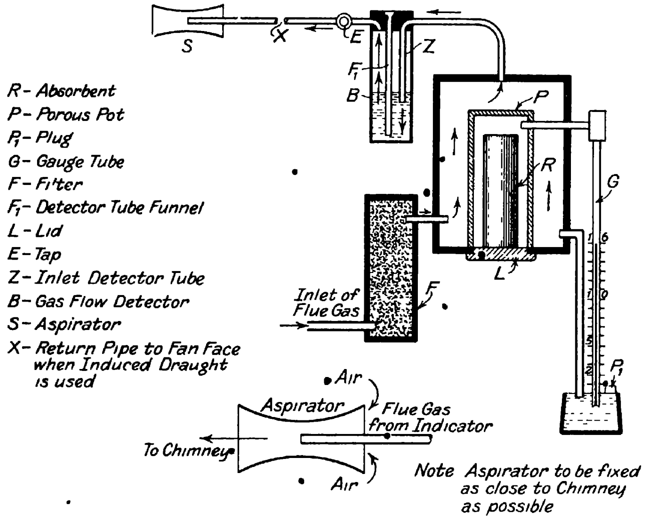

FIG. 137.—DIAGRAM OF THE W B COMBUSTION INDICATOR.

fans will vary with the densities of the gas and air respectively. The two fans are coupled together by levers which are joined by a link, and the whole system of levers will take up a position in which the torque of the air fan balances that of the gas fan. A pointer connected to the system indicates on a dial the percentage of carbon dioxide in the gases, with a time lag of a few seconds, the fans running at about 3,000 revolutions per minute.

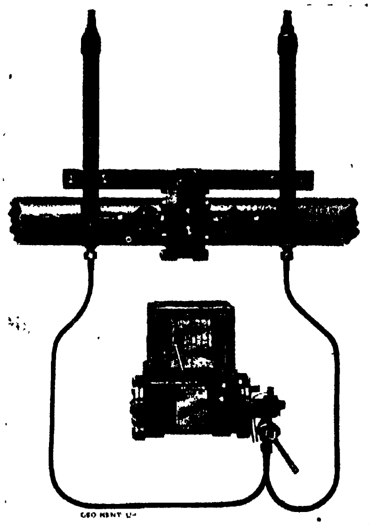
FIG. 138.—KENT DIAGRAM RECORDER.

The total water supplied to the boilers by the pumps is measured by the water meter, but it is often desirable to measure the steam supplied to any one department separately, and if any condensed steam is returned direct to the boilers a steam meter must be used. There are various types of steam meters, of which the Kent diagram recorder, shown in fig. 138, may serve as an example.

A carefully calibrated orifice is employed for obtaining the differential pressure by which these meters are operated. The type of orifice is shown in fig. 140. It fits inside the bolts connecting two flanges of the steam pipe line. The orifice fitting is made with an orifice plate to suit the load required, and has a range of full to one-fifth full load.

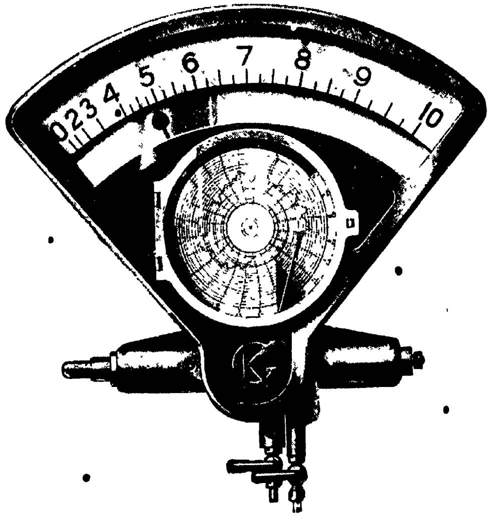

FIG. 139.—KENT BOILER LOAD INDICATOR.

In large central power stations it is very often convenient to know the exact evaporation of each separate unit, and for this purpose each boiler may be fitted with a load indicator. Fig. 139 shows a Kent combined boiler load indicator and recorder.

The principle of the instrument is similar to that utilized in the steam meter. The indicator is operated on the differential pressure system; by the insertion of an orifice plate $\frac{1}{16}$ inch thick in the steam main between the flanges differential pressures are set up. These two pressures are transmitted respectively to two cooling chambers in which the steam is condensed. Then, using water as a medium, the pressure is transmitted through two pipes to the opposite sides of a diaphragm. The diaphragm is controlled by two springs in tension, and when actuated by the difference in pressure controls a needle which indicates on the 18-inch dial the amount of steam passing at any instant. This reading is uncorrected for variation in pressure or superheat, and has to be modified from a table of factors covering the specific range required. The table of factors is supplied by the makers. The dial is generally graduated to read pounds of steam per hour.

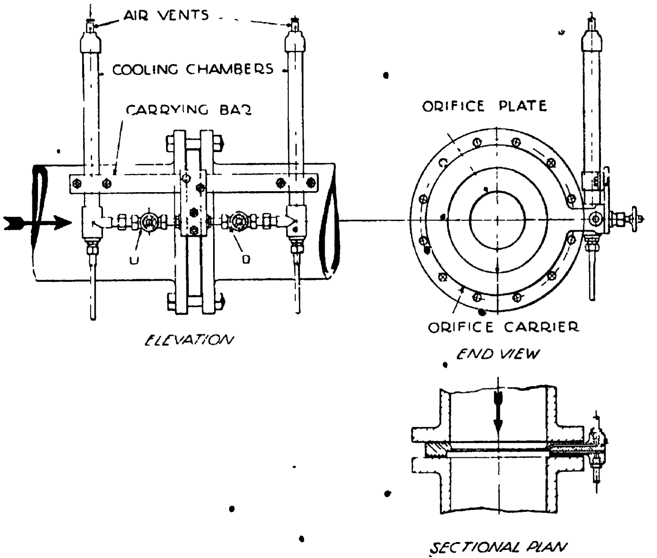

FIG. 140.—KENT STEAM METER ORIFICE FITTINGS.

The positions of the various instruments are shown, for a Lancashire boiler plant, in fig. 141.

The boilers should be provided with wrought-iron pipes built in an air-tight manner into the brickwork, and the pipes should be fitted with a tee-piece and plug whenever possible, so that soot or other sediment may be removed at any time by inserting an iron rod.

Fig. 142 shows the positions of the test holes for a Stirling boiler, and fig. 143 gives similar information for a Babcock and Wilcox C.T.M. type water-tube boiler.

The remaining instrument used by those in charge of boilers is the salinometer or, as it is sometimes called, the hydrometer. A salinometer is an instrument for measuring the density of the boiler water, and is of special interest to marine engineers.[1] It consists, as shown in fig. 144, of a graduated stem supported by a float.

It is generally constructed of metal, but for finding the density of heavy liquids it is made of glass and loaded with a mercury bulb. If a proper salinometer pot is not available, an ordinary bucket may be used to collect the water to be tested. The salinometer is placed in the water, and the depth to which the stem is immersed when the instrument floats in the container indicates the density of the liquid. It is important that the temperature of the liquid should be that for which the salinometer is graduated, because the density varies with the temperature. Most salinometers are graduated for use at 200° F.

To fill a salinometer pot from a boiler at, say, 200 pounds pressure is not so simple an operation as might appear. When the cock is opened, much of the escaping water is immediately converted into steam at atmospheric pressure; there is much spluttering, and care is needed to avoid scalds while the pot is filling. The stems of salinometers used in the mercantile marine are graduated in thirty seconds, because sea-water contains 5 ounces of salt in solution per gallon or one thirty-second of the weight of a gallon of fresh water (160 ounces). In taking boiler densities with these instruments, therefore, it is easy to ascertain to what extent, if any, sea-water has leaked into the closed feed-water system.

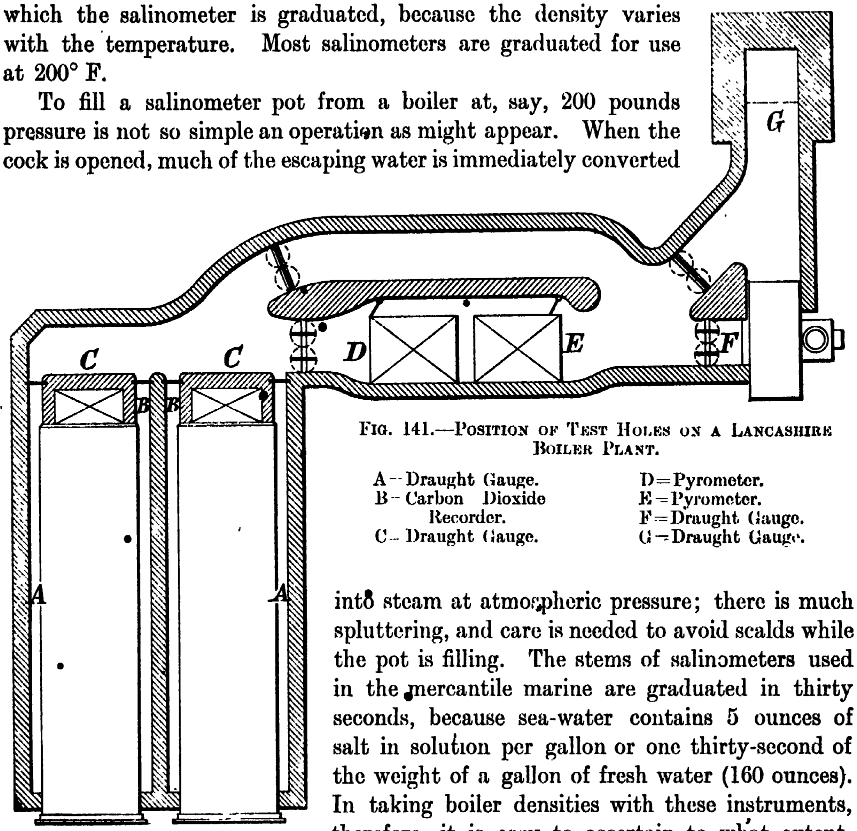

FIG. 141.—POSITION OF TEST HOLES ON A LANCASHIRE BOILER PLANT.

A—Draught Gauge.
B—Carbon Dioxide Recorder.
C—Draught Gauge.
D=Pyrometer.
E=Pyrometer.
F=Draught Gauge.
G=Draught Gauge.

The Admiralty hydrometer is graduated in degrees, every degree indicating ½ ounce solid matter dissolved per gallon. A gallon of sea-water will show 10 degrees, or the equivalent one thirty-second, as shown on the ordinary salinometer.

Chemists generally express density in degrees Twaddell, whilst continental manufacturers discuss degrees Beaumé. Figs. 145 and 146 show the relationship between these different scales, and are useful for converting one into the other.

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[1] *Verbal Notes and Sketches*, W. J. Southern.

Boilers may be worked with safety where the stem of the salinometer stands out of the water to the extent of one-half of a thirty-second, indicating $2\frac{1}{2}$ ounces of salt per gallon, but the boiler must be kept under observation both for priming and for corrosion if this figure is exceeded. It is very undesirable to work above one thirty-second. Water-tube boilers must not exceed three-quarters of a thirty-second– that is, the salt in the water must be limited to $3\frac{3}{4}$ ounces per gallon.

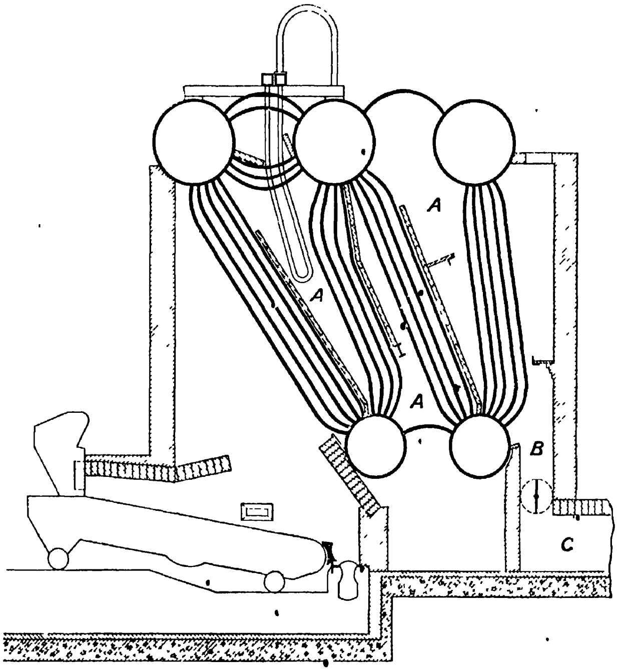

FIG 142 - POSITION OF TEST HOLES ON A STIRLING BOILER

A Draught Gauge
B Draught Gauge and Carbon Dioxide Recorder
C Pyrometer

The method of taking a sample of fuel for analysis has already been described. After the procedure detailed on p. 154, the sample is pounded in a mortar in the laboratory until an exceedingly fine powder is obtained. There are various types of fuel calorimeter, one of the best known being the "Sarco" bomb calorimeter shown in section in fig. 147.

The bomb consists of a strong phosphor bronze cylinder, gold and platinum lined on the inside to ensure long life. It is fitted with a cover secured by three large studs. With the cover is incorporated a needle valve for admitting oxygen,

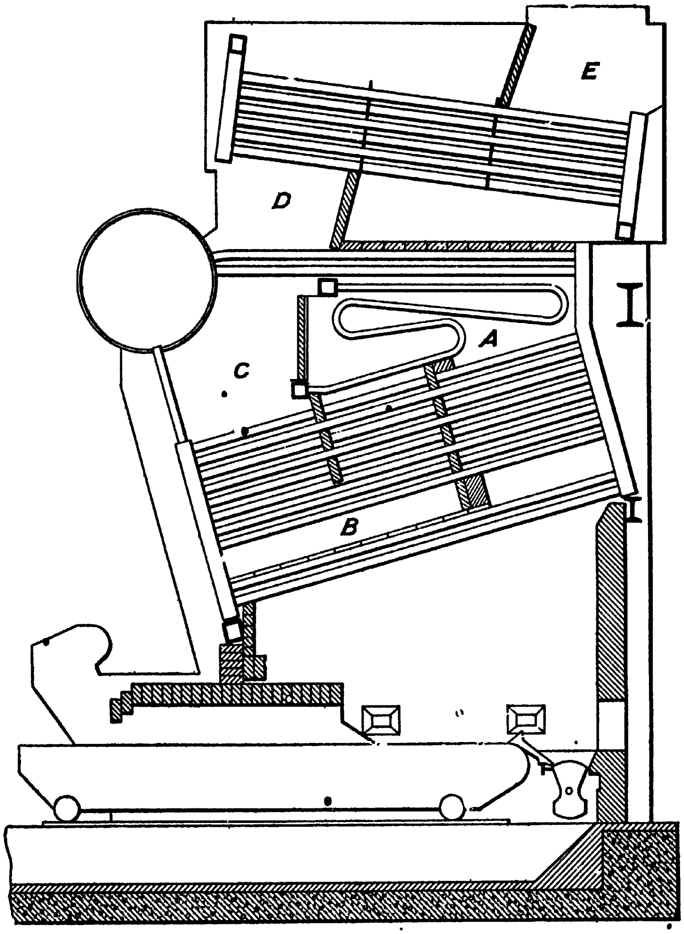

FIG. 143.—POSITION OF TEST HOLES FOR A BABCOCK AND WILCOX BOILER.

A = Draught Gauge.
B = Draught Gauge.
C = Carbon Dioxide Recorder.
D = Draught Gauge and Pyrometer.
E = Draught Gauge and Pyrometer.

and also a special joint through which the firing wire passes. The bomb is entirely surrounded by water, which is kept agitated after the charge has been exploded. The stirring mechanism consists of a couple of long vertical paddles, which are rotated by the handle at the top of the instrument through a pair of bevel wheels. An outer annular chamber, also filled with water, and an intervening air-space maintain the conditions of the field quite constant immediately outside the container, and the radiation is almost constant.

A small crucible is weighed on a chemical balance, and after about 2 grams of the fuel have been placed therein the whole is reweighed. The crucible is next placed in the adjustable holder attached to the cover, and the height regulated in such a manner that the loop of very thin wire just touches the fuel. The cover is replaced in the bomb and securely fastened by screwing down the three nuts An oxygen cylinder is connected to the bomb, and the needle valve in the centre of the cover opened carefully to admit a charge of oxygen, but not fast enough to blow all the powdered fuel out of the crucible. The needle valve is then closed, as is also that on the oxygen bottle. The pipe is disconnected, and the bomb placed in the calorimeter. The terminals from three dry cells or a special hand-driven dynamo are connected to the bomb, and the stirring mechanism connected to the handle.

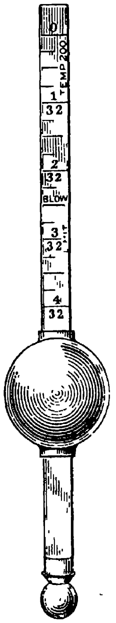

FIG. 144.—SALINOMETER.

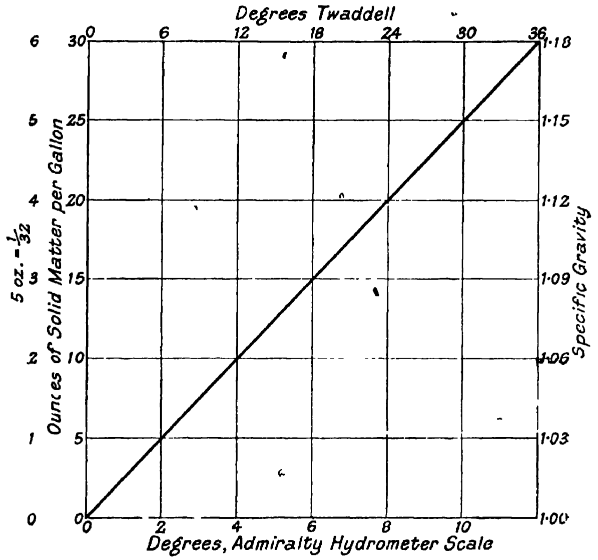

FIG. 145.—RELATIONSHIP BETWEEN VARIOUS UNITS OF DENSITY

The water in the inner chamber, the weight of which must be known exactly and therefore remeasured for every test, is gently agitated until the temperature recorded by a finely divided thermometer is constant. The charge is fired, and the water again quietly stirred until the highest temperature is recorded. Then the water equivalent of the apparatus *plus* the weight of water in the apparatus, multiplied by the rise in temperature and divided by the weight of fuel, gives the heating value of the fuel.

$$\frac{(E+W)T}{F} = \text{number of British thermal units.}$$

Since all chemical balances weigh according to the metric system, all the calculations may be done in grams, that is, the water measured in cubic centimetres, and the final result divided by 1·8 to convert the calories to British thermal units.

When working with these units a Centigrade thermometer must be used. Mistakes often occur through using a Fahrenheit thermometer and neglecting to convert.

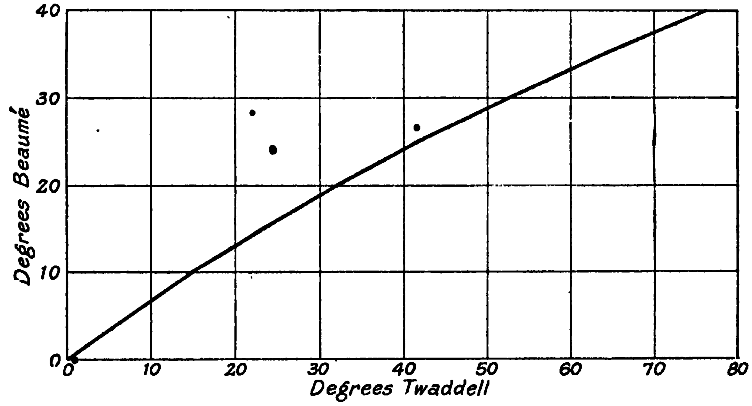

FIG. 146.—RELATIONSHIP BETWEEN DEGREES BEAUMÉ AND DEGREES TWADDELL.

To determine the water equivalent a known quantity of some combustible matter, the calorific value of which is known, is exploded in the calorimeter, and the value *E* solved from the equation given. Only those firms which employ a chemist in the boiler department laboratory will analyze their fuel, because the other employees have generally no time to spare for this work, even if they are competent to perform it.

Since it is essential to know the heating value of a fuel if any efficiencies are to be worked out, the following alternative method is here given. It has been taken from Mr. T. Roland Wollaston's book, *Power Plant.* No expensive apparatus is required, and the procedure, though simple, gives extremely satisfactory results. As this method has been successfully operated on board ship without the convenience of a firm of chemical apparatus dealers to supply requisites, it can be adopted by engineers in charge of plants situated far from any large town.

The ascertainment of the moisture, volatile matter, fixed carbon and ash is of great value for the purpose of making sure that the quality of the fuel delivered is constantly maintained. The necessary apparatus consists of an ordinary chemical balance, a small crucible of silica, with a lid, a Bunsen burner, pipe-clay triangle, and tripod stand.

To find the moisture, weigh the crucible without the lid, place in it about 2 grams of powdered fuel and reweigh. Then place it in a dry and evenly warm place—for instance, on the top of a steam pipe or gas stove, or inside a kitchen oven. After half an hour reweigh, and note the weight; repeat the operation after a quarter of an hour, and continue to do so until the weight remains constant. Then subtract the lowest weight from the original weight, divide by the original weight, and multiply the quotient by one hundred. The result will give the percentage of moisture.

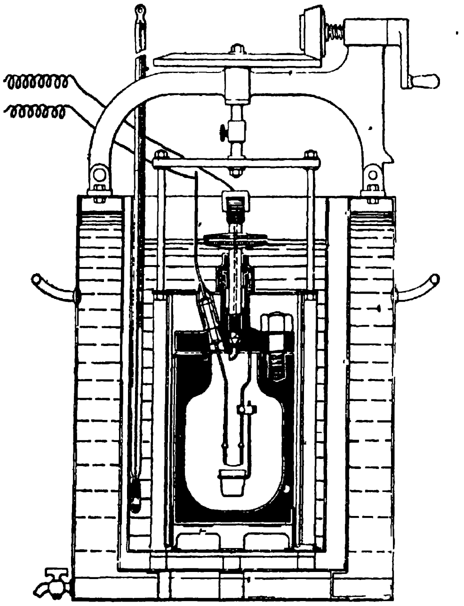

Fig. 147.—Sarco Bomb Calorimeter

To find the volatile matter, place the crucible, with the dried sample, on the tripod stand, as shown in fig. 148, and cover it with the lid, which should be a good fit and have a hole, measuring $\frac{1}{16}$ inch in diameter, drilled in the centre.

Regulate the Bunsen burner so that the flame is 6 inches high. The upper part only of the flame should envelop the crucible. It is most important that the distance between the bottom of the crucible and the orifice of the burner should be the same every time, and if the supply of gas is fairly constant, this distance may be 5 inches. After a few seconds a flame applied to the hole in the lid will ignite the escaping gas. From the moment of ignition continue the heating for *ten minutes;* then remove the burner. Allow the crucible to cool in a dry atmosphere. A wine-glass over a glass plate covered with vaseline may be used as a "desiccator." Reweigh when cool, and subtract the weight thus obtained from the "dry" weight ascertained in the moisture test; divide by this dry weight, and multiply by one hundred. The result will give the percentage of volatile matter.

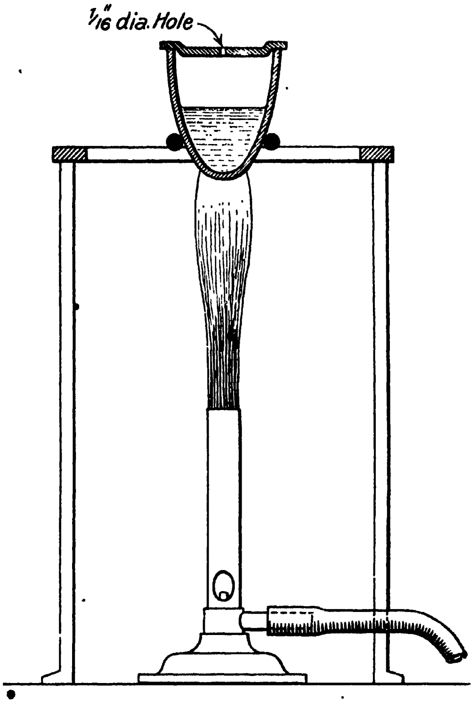

FIG. 148.—TEST FOR VOLATILE MATTER IN COAL.

To find the ash content the crucible, with its coked content, is again placed on the tripod stand over the Bunsen burner, but this time well down in the flame, and with the cover removed, as shown in fig. 149, so that the carbon may be fully consumed with free access of air.

When combustion appears to be complete—by the ash assuming a lighter colour—remove, cool, and weigh again under exactly the same conditions as in the "volatile" test. After weighing, it will be well to turn the ash gently over or to stir it with a piece of wire, and to return it to the flame, cooling and reweighing it to be absolutely certain that combustion is complete. The loss of weight, divided by the weight of the coke and multiplied by one hundred, will give the percentage of fixed carbon; while the actual weight of the unconsumed residue is, of course, that of the ash present in the original weight of dried fuel.

In connection with these tests Mr. Wollaston suggests the following adaptation of the well-known Goutel formula worked out by Mr. W. Briscoe Baron.

If C equals the percentage of fixed carbon in a fuel, if V equals the percentage of volatile matter in a fuel, then $145{\cdot}4\,C+aV$=the calorific value in B.T.U., where a is a constant which may be determined from the graph shown in fig. 150.

To find a, work out $\frac{100\,V}{C+V}$ and draw a horizontal line through the point corresponding to this value, and where it cuts the curve drop a perpendicular

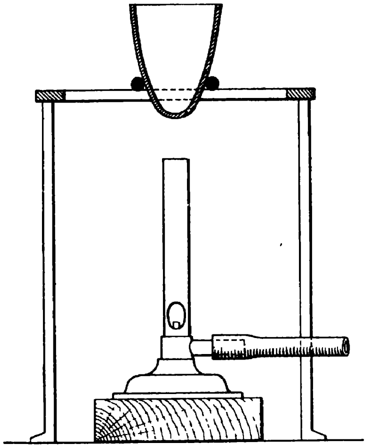

FIG. 149.—TEST FOR ASH IN COAL

on to the horizontal abscissa and read off the value for the constant *a*.

It will be gathered that there is nothing difficult about these tests, but, nevertheless, pains must be taken to obtain correct results. The simplicity of the method in no way dispenses with the need for care. With care and real interest results can be obtained which will differ but slightly from those obtained in the laboratory, and which will certainly be sufficiently accurate for practical comparison of the values of different consignments of fuel. The simplicity of these tests may lead to their use in plants in which a qualified engineer-chemist is not yet employed, and when experience has demonstrated that results *can* be obtained, and the utility of the information gained has been fully realized, a demand may arise for more scientific apparatus, which, in turn, will form the nucleus for a proper laboratory, ultimately requiring the services of an engineer-chemist who will apply methods of scientific control to the entire boiler plant.

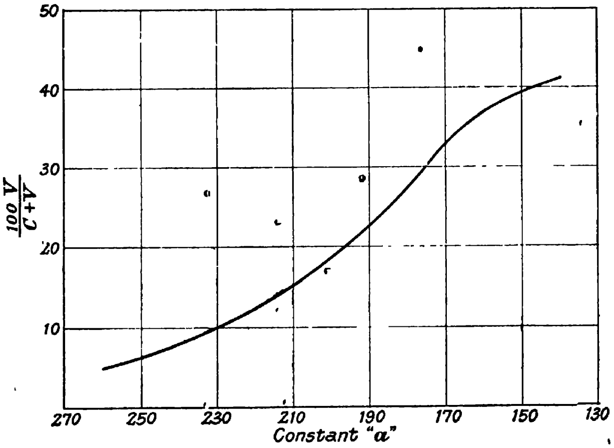

FIG. 150.—GRAPH TO DETERMINE "*a*" IN THE FORMULA $145.4C+aV$, WHEN CALCULATING CALORIFIC VALUE FROM PROXIMATE ANALYSIS

CHAPTER XIV

TESTING

(*a*) *Power Unit.*—Boiler houses which are under scientific control all the year round need no special test in order to ascertain their efficiency. The continuous records, if properly kept give all the information required, and are of far more use than any individual test, even if this last for a week. In such boiler plants special tests will only be undertaken very occasionally, as when a new boiler has been installed and the owners wish to conduct a test of their own in addition to that of the firm supplying the boiler. Generally such tests are conducted by the contractors' staff under the close supervision of the owners' representative, and the owners have only to concern themselves with the arrangement of the details.

Elaborate tests are usually limited to large installations, and even here difficulty arises from the lack of a satisfactory boiler-testing code. That prepared by the Institution of Civil Engineers has been out of date for some time, and the deliberations of the various professional organizations which are considering the formulation of a new code are still in progress. Pending the issue of an authoritative code, readers desirous of pursuing the subject further will find in Mr. David Brownlie's book, *Boiler Plant Testing*, a very thorough treatment of the problems involved. Although handicapped by the absence of a standard code, the engineer-chemist of an ordinary industrial boiler plant can do much to check misinterpretation of test figures and to ensure that the tests are so conducted as to give results which will be substantially correct.

Unless there is something radically wrong, no such elaborate testing will be necessary when an ordinary Lancashire boiler is installed in a factory boiler house, as would be required with water-tube boilers in a super-power-station unit having an average evaporation of 150,000 pounds per hour, and comprising mechanical stoker, superheater, economizer, air heater, forced and induced draught fans, pumps and other subsidiary apparatus. The engineer-chemist will only carry out special tests in order to arrive at some result not furnished by the continuous records—for instance, when a special fuel is to be tested or when a new arrangement of boiler setting or reorganization of flues has been undertaken on part of the plant. Separate fuel and water records must, of course, be kept in respect of the boiler under test. In other words, the weight of water and fuel consumed during the trial must not be included with that used by the remainder of the plant. In addition to the ordinary readings special data will be collected and tests will be made with the Orsat apparatus to fix the percentages of carbon monoxide, dioxide, and oxygen, in the flue gases. The fuel sampling must be carried out with special care, because it is vital to the success of the test to obtain an accurate sample, since the heating value of the fuel is the most significant factor in the final calculation.

In view of the extreme importance of obtaining an accurate figure for the heating value of the fuel, some firms keep a special boiler for experimental purposes, and this unit is practically in charge of the laboratory staff, although the steam generated is supplied to the factory on exactly the same terms as that coming from the other boilers. The testing plant is an independent steam-raising unit, has its own auxiliary appliances, subsidiary plant and separate flue, and is fitted with all the necessary instruments. In one large plant with which the author is acquainted, very careful testing over a period of many years has produced absolutely reliable data regarding the efficiency of this unit when fired with various kinds of fuel. Long-continued observation and experiment have made it possible to eliminate all the constant factors and to draw correct inferences regarding the influence of any new factor, such as a change of fuel. When a different class of fuel is about to be purchased for the main boiler plant, which comprises forty Lancashire boilers, a small sample quantity is burnt under the experimental boiler, and the factors of evaporation and calorific value are obtained independently of any analysis and coal sampling. The possibility of error when burning a hundred tons of fuel under the experimental power unit, in which radiation losses and all other characteristics are known, will be less than when determining the heating value in the laboratory after taking a coal sample, because certain allowances have to be made to convert the calorific value of the dried fuel in the calorimeter into that of the fuel in the condition in which it is supplied to the boilers.

Very few firms as yet have such an experimental station, but in large power plants an accurate comparison between different fuels under working conditions may thus be obtained, which can only have an important influence on the choice of supply. Large savings may often be effected by attention to this matter, especially when the fuel bill runs into five and six figures. In this connection it is well to remember the formula:

$$\text{Gross efficiency} = \frac{\text{heat returned in steam}}{\text{heat supplied in fuel}}$$

Several factors enter into net efficiency calculations, the two most important being the heating value of the fuel and the steam used by the auxiliary machinery assisting in the production of steam. Questions affecting the allowances which should be made when the coal actually burnt in a test differs from that on which the manufacturers' guarantee figure is based, and the inclusion or exclusion of steam supplied to auxiliary appliances when calculating efficiencies, have given rise to such divergence of opinion that their discussion is a main cause of the delay in formulating the urgently needed testing code. Differences in methods of calculation in these respects make all the difference in the last few per cent. of a guaranteed efficiency.

For the vital purpose of calculating *comparative* efficiency from week to week, the engineer-chemist need not be troubled by such controversies. If he works the results out in the *same* manner every week he will obtain an *index* figure by means of which he can detect any serious loss of efficiency in a particular week, and set on foot enquiries to ascertain the reason. The consumption of the steam jets will be tested from time to time in order to make sure that the jets are not becoming worn, and that the fuel burnt to supply them is not out of all proportion to their utility. In arriving at the net boiler efficiency every week the engineer-chemist will deduct the steam consumed by the jets at the last test. As his staff have other more important work to do than testing steam jets every week, he may disregard any small error that creeps in as a result of slight variations in the steam consumption of the jets. In view of the fact that very few firms as yet take the trouble to keep records, to say nothing of calculating efficiencies, and that a general race between boiler plant owners in the different industries to determine who can run his plant at the highest efficiency has not yet taken place and has not even been announced, *minutiæ* of this character can for the present be treated lightly in *continuous* records. These records are only of service for comparison with past performance of the same plant; they can only become valuable for comparison between different plants when an agreement has been reached and embodied in a code dealing with such vexed questions as those mentioned above.

(*b*) *Auxiliary Appliances.*—The auxiliary plant should be tested independently whenever the continuous records show an unusual waste. A superheater may not contribute its share towards the general efficiency of the plant, and this may not be noticed at once, because the steam temperature will probably be recorded by an instrument fitted in the main steam-pipe range. Superheaters are fitted with thermometer pockets, and it is an easy matter to insert a thermometer and take the temperature of the steam leaving any one superheater. If more accurate information is required a steam meter can be inserted between the boiler and the superheater, and a test made over a certain number of hours, measuring the steam passed through the superheater, inlet and outlet temperature, temperature of the flue gases before and after passing through the apparatus. Analysis of the flue gas may also be made to ascertain the specific heat.

The economizer can be tested in a similar manner, substituting water meter for steam meter, although the continuous records should give all the information required concerning this apparatus, because in general practice all the feed water passes through the economizers, which are either in one straight line or so located that the gases pass through in parallel. If any condensed steam is returned to the boilers direct, such as condensed steam from tentering (known in Lancashire dialect as "stentering") or other process machinery, a steam meter must be inserted between the boiler and the machinery using the steam. The steam cylinders of such machines are really part of the steam space of the boiler, because the whole pipe line and machine are at boiler-pressure, and the condensed steam returns to the boiler under the action of gravity. If there are many machines the water returning to the boiler is a large percentage of the total steam evaporated. The desirability of keeping close watch upon the quantity of steam used by the auxiliary machinery has repeatedly been emphasized. An occasional test should be made by weighing the condensed steam. Such tests cost money, and need only be carried out, on an average, twice a year. In the intervals the indicator will provide what information is necessary.

Indicating an engine takes very little time, especially in a works where the mechanic knows the sizes of the various fittings. The fan, economizer, mechanical stoker, and centrifugal pump engines should be indicated as well as the reciprocating pumps. Figs. 151 to 155 show a few indicator cards with their respective faults:

Fig. 151. Card from an engine fitted with a piston valve admitting steam at the centre. When overhauling valve gear, the piston rings were replaced incorrectly. Top end is correct, and card remains unaltered; bottom shows cut off too early.

Fig. 152. Card shows very leaky piston rings.

Fig. 153 Card shows effect of leaky piston rod gland.

Fig. 154 Card is off an engine working with an expansion valve located at the back of the main slide valve, main slide valve is low.

Fig. 155 shows a card from a circulating pump engine exhausting into a condenser, grooved piston rod

(c) *Subsidiary Plant.* -The subsidiary plant will require little attention beyond what might be termed "checking" or calibrating tests. Automatic fuel weighing appliances should be checked by reweighing a known quantity of fuel and comparing with the weight registered by the machine This may conveniently be done by collecting one or more charges of fuel on the boiler-house floor and reweighing in a basket standing on a weighbridge or attached to a steel yard.

Water meters should be arranged as shown in fig. 79, so that a certain quantity of water may be passed through the apparatus into a tank, and the volume measured. The piston rings in pressure meters become worn and allow water to pass, or the "change over" cock may by-pass a little water. The simplest way of calibrating water meters is to install a tank near the meter and insert a tee-piece in the discharge pipe from the meter with a branch pipe and valve leading to the tank. At any time, and without trouble, the discharge valve to the feed range may be shut, and the valve on the branch pipe opened. The tank can be filled and the volume of water found by multiplying the area of the tank by the depth of the water. This figure converted into gallons should, of course, be the same as indicated by the meter clock. If the meter does not measure correctly, it is of little value carefully to record the volume of water evaporated every day.

It has been mentioned that the duties of the laboratory staff include the undertaking of such investigations as may appear necessary from time to time Such an investigation might be to ascertain the condition of the pipe covering, and the simplest way of determining whether the insulation on the steam pipes has deteriorated in any way is to compare the dryness of the steam at different points in the pipe line. This may be accomplished by using a wire-drawing calorimeter. The apparatus is illustrated in fig. 156.

The operation is as follows: The steam passes through the inlet valve; the pressure and temperature are shown on the gauge and thermometer respectively, and should correspond according to the steam tables. The steam then passes through

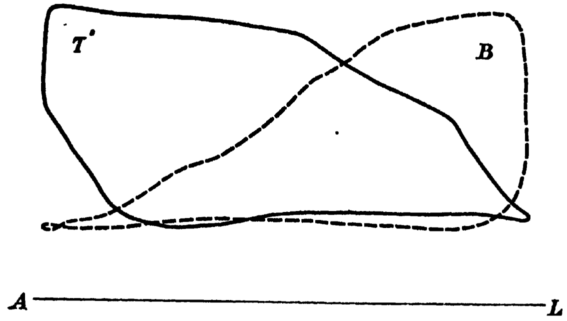

Fig. 151.

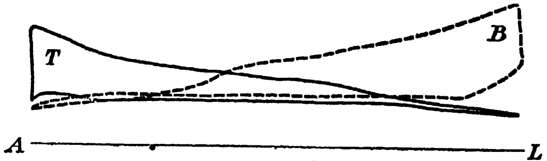

Fig. 152.

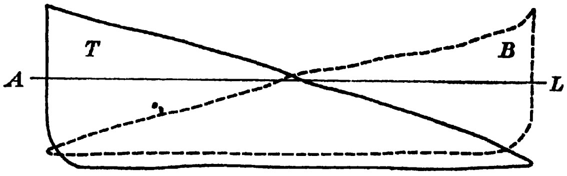

Fig. 153.

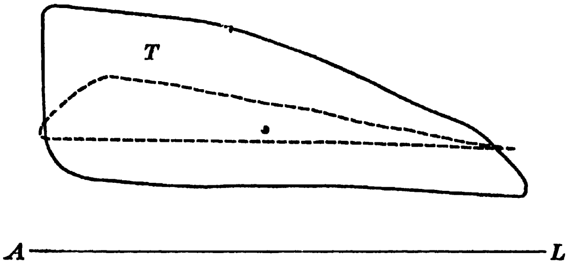

Fig. 154.

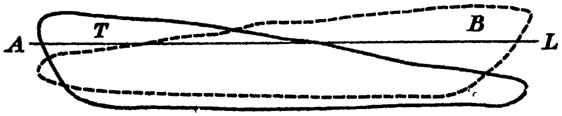

Fig. 155.

Indicator Cards.

a hole, $\frac{1}{16}$ inch in diameter, in a metal disc clamped between two flanges. In forcing its way through the small hole the steam becomes slightly superheated on account of the wire-drawing action of the disc, and the rise in temperature is proportional to the moisture in the steam. The outlet temperature is observed at the thermometer provided, and the steam leaves by a pipe sufficiently large to prevent an accumulation of back pressure. Since the accuracy of the results depends on the exit temperature of the superheated steam the apparatus must be well lagged. If S and L represent respectively the sensible and latent heat of wet steam in the main pipe, and T the temperature of the superheated steam as shown by the outlet thermometer, then

$$\text{Dryness} = \frac{1051{\cdot}5 + 0{\cdot}167\ T - S}{L}.$$

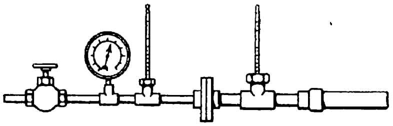

FIG 156 WIRE DRAWING CALORIMETER

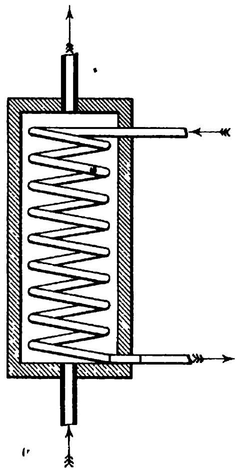

FIG. 157 – SURFACE CONDENSER CALORIMETER.

An alternative method is to use a surface condenser calorimeter as shown in fig. 157. This can readily be made in the workshop.

In order to ascertain the efficiency at which a boiler is working the following formulæ may be used:

Let W equal the pounds of water evaporated per pound of fuel burnt.
,, H ,, total heat in one pound of saturated steam.
,, S ,, heat in 1 pound of steam due to superheating.
,, F ,, ,, ,, feed water at inlet temperature.
,, C ,, ,, ,, fuel.

$$\text{Then thermal efficiency} = \frac{W(H - F) \times 100}{C} \text{ if steam is not superheated.}$$

$$\text{If the steam is superheated, thermal efficiency} = \frac{W(H - F + S)}{C}.$$

The evaporation of water per pound of fuel "from and at 212° F." is equal to

$$\frac{W(H - F + S)}{970}.$$

The heat in 1 pound of steam due to superheating is equal to the degree of superheat multiplied by the mean specific heat at the observed pressure.

PART II

MAINTENANCE

SECTION V.—UPKEEP OF POWER UNIT

CHAPTER XV

INTERNAL INSPECTION

We have been considering the application of the principles of scientific control to the operation of steam-raising plant. The object has been to set forth all the items to which the engineer-chemist must give attention if he wishes to obtain from the boilers under his charge the highest efficiency of which they are capable.

The capacity of a boiler plant is, however, limited by its physical condition, and no amount of good management will obtain the best results from apparatus which has been allowed to get into bad repair. Obviously, therefore, the engineer-chemist must tackle the problems of maintenance no less thoroughly than those of operation. Moreover, the vital question of safety is bound up with good maintenance. Even those who are indifferent to efficiency cannot disregard the possibilities of destruction involved in a boiler explosion; and in a way this is a good thing, for otherwise a good many boiler plants would never receive any attention at all. Fig. 158 shows the effect of a Cornish boiler explosion.

In the case of machinery on board ship frequent Board of Trade inspections and Insurance surveys are compulsory and of great severity.[1] On shore the only legislation relating to the compulsory examination of boilers is that contained in the Factory and Workshop Acts, 1901 and 1907, Metalliferous Mines Regulation Acts, 1875 and 1882, and the Coal Mines Act, 1911. The Boiler Explosion Acts, 1882 and 1890 provide for an official inquiry to be made after the event whenever a boiler has exploded.

The gaps left by the Legislature have been filled by the insurance companies. Among the leading companies which have performed yeoman service throughout the period of their existence may be mentioned The National Boiler and General Insurance Co., Ltd., The Manchester Steam Users Association, The Vulcan Insurance Co., Ltd., and The British Engine, Boiler, and Electrical Insurance Co., Ltd.

In early days there was a tendency to regard boiler explosions as mysterious " acts of God "; then followed a period in which various fantastic theories flourished. It was held, for example, that explosions were caused by the sudden destructive flashing into steam of water when it came in contact with overheated metal. This idea was responsible for a delusion that prevailed for many years to the effect that boiler explosions were always attributable to a shortness of water. Enquiries instituted by the insurance companies have established the fact that boilers used to explode because, owing to faulty workmanship, defective seams and plates, or similar causes, they were not strong enough to withstand the pressure to which they were subjected.

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[1] *Practical Advice for Marine Engineers*, C. W. Roberts.

It was soon realized by the insurance companies that there only exists one method by which the problem of boiler maintenance can successfully be tackled, and that is by regular inspection.

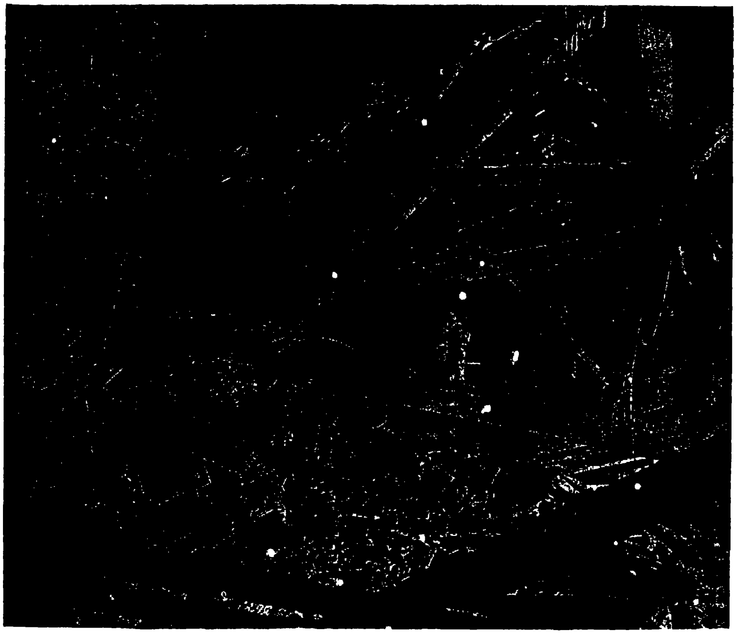

FIG. 158.—RESULTS OF CORNISH BOILER EXPLOSION.

Successful supervision depends upon a detailed consideration of every factor connected with the operation of the plant. So, also, a high standard of maintenance can only be achieved by very carefully watching each component part of the installation. The insurance companies cannot be continually examining a boiler plant, but they do the next best thing. They take very accurate records of every piece of apparatus, and by systematic periodical inspection keep the information right up to date, so that the exact history of all the parts is known, at least for the period during which the insurance company has been concerned with them. The proceeding adopted by The National Boiler Insurance Company is as follows:

Every boiler proposed for insurance is carefully examined in every part, full particulars of its structure taken, a drawing made, and its safe working pressure assigned.

Afterwards, as long as the boiler continues to be insured, it is inspected internally every year, any defects which may show signs of developing being kept under observation and the result of wear and tear being carefully noted. In this way the strength of the boiler is at all times a known quantity, and if any part is found to be weakening, either it is repaired or the working pressure is reduced within the limits of safety. In addition to the annual internal and external examination when at rest, the boiler is examined externally when at work, the special object of this inspection being to ensure that the fittings, such as safety-valve, water gauge, feed valve, and so forth, are in efficient order.

There are many plants in which the suggestions of the insurance company are not adopted in their entirety, whilst many others are never inspected at all. The insurance companies are all private institutions, and it is therefore the more remarkable and praiseworthy that they can show such wonderful records. A glance at the statistics of boiler explosions in Great Britain for the last fifty years will fully corroborate the truth of this view.

(*a*) *Opening Up.*—Boilers must be regularly opened for internal cleaning; how often will depend upon the nature of the feed water and the amount of water that has been evaporated. The exact period can only be determined by careful observation and a general consideration of all facts relating to the plant.

Generally, the impurity of the feed water sets a limit to the time which can be allowed to elapse between cleanings. The job should not be delayed for a longer period than is required for the formation of a scale $\frac{1}{16}$ inch thick. The accumulation of scale is very undesirable, not only because it retards the rate of heat transmission through the plates, but also because it prevents a thorough examination. As scale often conceals symptoms of corrosion, it is possible for some part of a boiler which is not regularly cleaned to become so weak, due to a gradual and undetected wasting away of the metal, that a serious explosion may result.

Certain precautions must be observed when preparing a boiler for internal cleaning. When the fires have died down, so that they will not increase the steam pressure in the boiler, the main stop-valve and any other steam connection taken from the boiler direct should be shut. The wheel should be taken off and sent to the store with a label attached, so that it may not be lost. As the boiler should cool down very slowly, two or three days should be allowed for it to do so.

When the boiler is cold the small cock on the pressure gauge, or any other fitting which is connected to the steam space of the boiler, should be opened. This procedure will serve a two-fold purpose. On the one hand, if there should still be a slight pressure in the boiler, the mechanic will notice the steam issuing. On the other hand, if the steam has condensed, the air can rush in to destroy the partial vacuum thus formed. Pressure gauges cannot be relied upon at very low pressures; they often indicate zero when there is still pressure in the boiler.

When the boiler is ready for emptying, the blow-down cock should be opened and the water run out. If any vacuum has not been destroyed, as described above, the atmospheric pressure will prevent any water leaving the boiler. Again, should the pressure in the boiler happen to be equal to that of the atmosphere, although no cock has been opened to equalize the pressures, the water will not run out of the boiler for very long. Soon a partial vacuum will be formed, and the atmospheric pressure will prevent the water from escaping.

As soon as the boiler is empty, the blow-down valve or cock should be shut in a proper manner and, in the case of a valve, the wheel removed and sent to the store to be kept with the steam stop-valve wheel. The feed-check valve should be tried to make sure it is shut, and the wheel removed also.

Many times a feed valve has been thoughtlessly opened whilst men were at work in a boiler, and deaths due to severe scalding have been the unfortunate result. A smart man can quickly get out of a Cornish boiler through the top manhole, but if he is working in a marine boiler right down between the furnaces and has to climb up between the tubes before he can reach the top, he may easily be suffocated by steam while trying to escape.

Boilers on shore may be emptied by running the water out as described, but the blow-down valve of boilers on board ship is always below the sea-water level. In that case the water has to be pumped overboard by drawing from the pipe system connected to the blow-down range (already referred to in Chapter III., on the subject of circulating boilers) and discharging overboard.

In some ships the boiler water is absolutely pure, and the boiler is opened, not for cleaning, but only for inspection. Under such conditions the water is often used for feeding the other boilers instead of throwing it away overboard. In that case the pump draws from the same source as in the previous instance, but instead of the water being pumped back into the same boiler it is forced into another one.

On most ships the boilers are blown down. In other words, the water is blown out through a discharge cock in the ship's side.

The practice of blowing down is generally followed on shore, and on account of the very limited time allowed for boiler cleaning often there is no alternative. The procedure is not good for the boiler, but the evil effects can be mitigated by allowing the pressure to drop a little before blowing down.[1]

The steam left in a boiler after it has been blown down must not be allowed to condense, and so form a vacuum. There are several cases on record where boilers strong enough to withstand 180 pounds per square inch internally have collapsed, due to atmospheric pressure externally. The load on a 30-feet long by 8 feet diameter Lancashire boiler with, say, a net atmospheric pressure of 10 pounds per square inch—that is, 20 inches of vacuum inside the boiler—will be sufficient to crush it out of recognition.

Other methods of emptying are sometimes adopted when the time available is very limited, but the boiler suffers severely when they are used, and they are heartily to be condemned.

[1] *Engineering*, No. 2081, p. 217.

The objectionable methods are as follows:

1. Pumping cold water through the feed-check valve as fast as the hot water runs out through the blow-down valve.

2. Blowing out the water under full boiler pressure. This is very bad for the plates and seams, on account of the unequal contraction of different parts of the mass of metal during the rapid fall in temperature. When this procedure is followed, the scale and deposit in the boiler become very hard, due to the drying effect of the latent heat in the metal.

3. Blowing down with full pressure and then allowing cold water to rush in. A boiler treated in this manner will " leak like an old pepper box." To illustrate the rapidity with which the change in temperature takes place the reader is reminded of the following elementary experiment. If a flask which has been filled with steam by boiling a small quantity of water is then inverted and the opening held under water, the water rushes into the flask almost instantaneously, the reason, of course, being that on contact with cold water some of the steam condenses, creating a partial vacuum, and the atmosphere then rapidly forces more water into the vessel. As the water increases in volume the process of condensation is accelerated and the water rushes in faster. Applying the same principle to a case in which there is a boiler pressure of 180 pounds per square inch, with the plates at the corresponding temperature—namely, 380° F.—we find that if water at a temperature of 60° is allowed to rush in, the initial drop in the temperature of the plates is 320° in about as many seconds.

It is also bad practice to use air to cool boilers rapidly by fixing a canvas shoot in the fan discharge casing of the forced draught system and inserting the other end in the bottom manhole. The boiler is certainly rapidly cooled, but it suffers in proportion.

When the boiler has been open for a day or two and is at atmospheric temperature, the matter is quite different, and artificial ventilation can well be adopted on a hot summer day, or on board ship in the tropics, when with a squad of natives chipping inside the boiler, the atmosphere tends to become overwhelming.

The importance of destroying any vacuum has been emphasized, because neglect of this precaution is constantly causing accidents, attended with grave danger to limb and life.

When opening a manhole the men should always work from the side, and never sit, kneel, or stand immediately in front of it. The proper procedure is to attach the manhole cover to a rope, take off the dogs and, with a long rod or piece of wood, to knock in the cover. Manhole covers invariably stick to the boiler. This is due to the nature of the materials used in making the joint.

Cases are on record where, the vacuum in the boiler not having been destroyed, men kneeling in front of the manhole lost their balance when the cover, held up by the adhesion of the joint, suddenly gave way. These unfortunates, pressed by the atmosphere *on to the opening* in the boiler, received injuries too awful to describe.

When the boiler has been opened, the engineer-chemist should thoroughly inspect it both internally and externally. He should make very careful notes about the condition of every part, and then give his orders for the work to be done. In this way much time will be saved, as, if repairs are to be executed, the boilermakers will not appear on the scene before the scaling is finished, or while the cleaners are still at work getting the plates into a fit condition for work to proceed.

It is the engineer-chemist's duty to give detailed instructions regarding any necessary repair work on the mechanical stokers, etc., and to see that any of the mountings or their component parts that require attention are taken to the workshop, where they can be efficiently handled. He should not tolerate such unworkmanlike scenes as a fitter struggling with a pair of foot-prints in one hand, trying, with a spanner in the other hand, to slacken a tight nut on a stud, when the job would be done in a fraction of the time by putting the stud in a vice.

Slovenly practice, such as taking valves adrift and placing the component portions in a corner, on the boiler, or in a jacket pocket, cannot be too strongly discouraged. Water gauge, valve, cock, or whatever it may be, should be taken into the workshop, where any work that may be necessary can be done properly at a bench. Faulty workmanship, or the admission of dirt, may mean that the boiler has to be shut down after restarting, and the job done over again, with a consequent waste of time and money.

From his notes made whilst the boiler was in operation, the engineer-chemist will know just what work requires to be done when the time arrives for it to be cleaned.

Before the inspection takes place the boiler should receive a preliminary cleaning, involving the removal of all matter from the grate and ash pit. In the case of Lancashire boilers it will also be necessary to sweep away all the soot in the boiler flues, clean the ashes away from the blow-down valve, etc. The inspection to detect corrosion is of a different character, and can only be undertaken when all parts have been thoroughly cleaned. In any case, work attempted amidst discomfort and uncleanliness will be uneconomical in the long run. Some of the specific troubles arising from the admission of dirt have already been indicated. Cleanliness should be the watchword of every engineer-chemist. A general idea of the conditions necessary for a proper inspection is given in the following general instructions:

1. The boiler should be accessible, cool, dry, and clean inside.
2. The plates and flues should be well cleaned of soot.

In order properly to fulfil these conditions the boiler should be opened out, cleaned, and scaled; doors of manholes, mud-holes, and hand-holes taken off; firebars removed, and, in the case of Lancashire boilers, the firebridges if of brick; all connections opened out; safety-valves taken adrift, cleaned, and readjusted. Where necessary, brickwork must be removed for the purpose of inspection of the vital parts of the external surface of the boiler. The cones or caps of the fusible plugs must be taken to pieces and cleaned for examination. The cleaning plugs of the water gauges will be removed and the passages thoroughly cleaned.

In detailing the items which require special attention in connection with each of the various parts it is somewhat difficult to distinguish between internal and external inspection. The plan here adopted is to regard internal inspection as concerned with all parts in contact with water or steam, whether the inside or outside surface is being examined. Thus, the boiler brickwork of water-tube boilers has been included in external inspection, although, to perform the inspection, it is necessary to " go inside the boiler."

(*b*) *Shell.*—The first part of a boiler to be inspected is the shell, which includes plates, seams, internal fittings, stays, and, in the case of tubular boilers, the smoke tubes.

The only instrument really required for boiler-cleaning is a wire brush, and hundreds of boilers never receive any other treatment than a sound brushing. These, however, are a minority. In a vast number of cases scale forms as a result of the use of impure feed water, and this must be removed by mechanical means or by hand chipping. In the old days there were numerous superstitions concerning the alleged beneficial effect of potatoes, tan-yard refuse, etc., in preventing the formation of scale.

On the subject of scale removal it should be stated that the use of boiler fluids is quite unnecessary, and most objectionable, being a lazy man's way of trying to achieve results by a short cut. Boiler fluids almost invariably contain caustic soda, a little tan-yard refuse and much water, which are sold in fancy containers at fancy prices. If caustic soda is to be introduced into a boiler—which is bad practice and only justifiable in very exceptional circumstances—it is safer, and incidentally much cheaper, to buy the raw material and apply it in a known quantity, than it is to use boiler fluids of unknown strength according to instructions prepared by manufacturers interested in selling as much of their product as possible.

One boiler fluid which was said to be superior to any other product of its kind on the market contained some kind of refuse from oil distillation, and, when dissolved in petrol, gave a liquid similar to engine oil. The result of using such stuff can well be imagined when we recall that it is an important part of the engineer-chemist's duty to prevent the least trace of oil from finding its way into a boiler. The price paid for the experiment by the owners of one set of boilers into which this compound was introduced amounted to the cost of expanding 320 tubes. For purposes of the final inspection for corrosion, the whole of the interior of the boiler must be absolutely clean, and as most boilers are covered with scale, this has first to be removed.

Where labour is cheap the scaling may be done by engaging a squad of men who remove the scale by tapping the plates with small hammers. Frequently the scale is very hard, and as the work does not proceed fast enough the men use sharp tools which injure the surface, offering every inducement for corrosive liquids to enter the grain of the metal. High wages and a general desire for " speeding up " all round have led to the use of scaling machinery.

A large variety of power tools have been perfected in order to facilitate the rapid removal of scale from the many types of boilers in use, but the " Skatoscalo " range of scaling tools made by Messrs. Frank Gilman (B.S.T.), Ltd., is designed to meet every boiler scaling and rust removing requirement. The tools are either pneumatically, electrically, or petrol driven, and are made in a variety of patterns for removing incrustations from both flat surfaces and tubes.

Fig. 159 shows some types of pneumatically driven tools. Type "A" is made in various sizes for scaling Lancashire, Cornish, marine, locomotive, vertical, and other boilers. Type "E" is designed for use with Babcock, Stirling, Woodeson, Climax, Belleville, and all tubular boilers, also for evaporators and economizers. A special design, type "AA," the main feature of which is a long chisel-headed piston, has been found of great value where it is required to remove extra heavy incrustation. The principle of action upon which these tools work is that of a piston or pistons with staggered heads, operated by compressed air and delivering up to 10,000 blows a minute on the face of the scale.

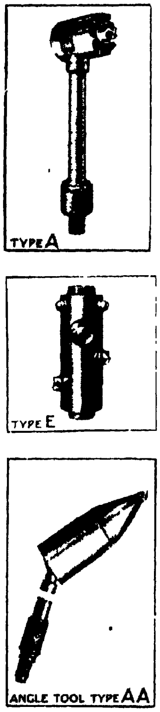

Fig. 159.—Types of Pneumatically-driven Scaling Tools.

When no air compressing plant is available, the electrically or petrol-driven types may be used. The working principle of both of these, which differs from that employed in the pneumatic type, is that of a revolving head with cutter wheels or wire brushes driven from the power unit by means of flexible shafting. The action of the scaling heads is that of effective utilization of centrifugal force. The three cutter wheels in the hammer head mechanism have large bores, and hang loosely upon the bolts. When the head is revolved rapidly these cutters fly out with great force against the scale.

The petrol-driven apparatus consists of a two-stroke petrol engine, developing up to 2½ h.p., and driving a flexible shaft to the end of which is fixed the scaling head. This apparatus has been found of special value for use in districts remote from any source of power supply.

The electrically driven apparatus, shown in fig. 160, is a portable unit consisting of a small electric motor of 1½ h.p. (any voltage), and can be fitted ready for use to any lighting or power installation.

In the case of Lancashire and similar boilers the first belt of the shell plate should be very carefully examined for pitting, especially round the blow-down cock. Pitting may be local, or it may be spread over a wide area. It shows itself by holes in the plate. These may be close together or far apart. Most frequently they are close together, and are small and deep, rather than large and shallow, although their size varies according to the nature of the feed water and the quality of the steel. The smallest are no larger than a pin hole.

Pitting is an example of corrosion by oxidation, and the remedy is to clean the part thoroughly. Every trace of dirt, scale, grease, etc., should be removed, and the plate affected should be painted with a thin cement wash. The same place must be very carefully examined the next time the boiler is opened.

Another place at which pitting is often found is at the water level of the boiler, along both the sides and end plates. It is here that the air escapes from the water, and the liberated oxygen in its nascent condition is very powerful. A thin scale, about $\frac{1}{64}$ inch thick, which has intimately bound itself to the steel plates, is the best remedy for boilers troubled in this way. So thin a scale will not interfere greatly with the steaming capacity of the boiler, but it is absolutely necessary to make sure that such a scale is a real ingrained protective covering, and not a casual coating which can easily be removed, and underneath which corrosion may go on unseen.

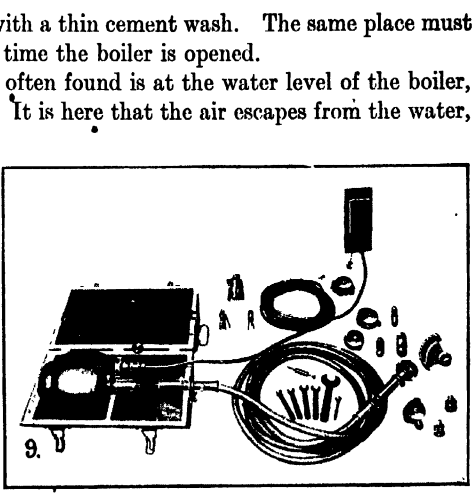

FIG. 160.—ELECTRICALLY-DRIVEN BOILER SCALING OUTFIT.

In water-tube boilers the flanges of the drum end plates require careful examination as they often show signs of grooving, though this frequently proves exceedingly difficult to detect, firstly, because the drums are relatively small in diameter, and secondly, because the grooving is invariably of the hair-line variety and nearly always appears right at the root of the flange. Should there be the slightest sign of hair-line grooving the engineer-chemist must make a minute examination of the bend of the flange, remembering that the end plates are never stayed. These hair-line grooves may be cracks going right through the plates, and if their discovery is left until a plate blows out, the damage may be very serious.

Whilst making an inspection of the shell plates the seams must be closely examined. The very high stresses set up when too rapid cooling or faulty circulation causes wide differences of temperature in the various parts always affect the seams of a boiler. Corrosion due to galvanic action between the shell and the butt straps is also common, the two plates seldom being of a homogeneous character. Another form of corrosion is that known as grooving, which frequently runs right along a seam.

Mechanical straining due to unequal expansion is an item quite by itself, and must not be confused with fatigue due to a constant strain produced by alternate heating and cooling or by subjection to high and low pressures. For instance, the angle ring whereby the front plate is attached to the shell of a Lancashire boiler will, in at least one installation out of every four, be found grooved as a result of stresses set up by the difference in expansion between the flue and the shell.

In order to overcome the thrust of the flues held rigidly between the front and back plates of the boiler, some makers introduce into the furnace a number of hoops which take up the expansion. This is not sufficient, because the hoops in themselves are too stiff, and the proper method is to make part of the flue corrugated in exactly the same manner as marine boilers are fitted with corrugated steel furnaces. An example of such a boiler is that manufactured by Messrs. John Thompson of Wolverhampton, as shown in fig. 161.

Whilst examining the shell the engineer-chemist should look at all openings for the boiler mountings and fittings, with special reference to the gauge glass holes, to make sure they are perfectly clear. Cocks are often screwed into the shell, and, being made of brass, these corrode fairly rapidly. All such fittings should be fixed by a flange and four ¾-inch studs, but where the screwed type is used the engineer-chemist should satisfy himself that the thread is sound, and that there is no danger of the cock being blown out. Salinometer cocks are often a source of trouble in this respect, and the nut on the inside is not sufficient protection against either leaking or a "blow-out."

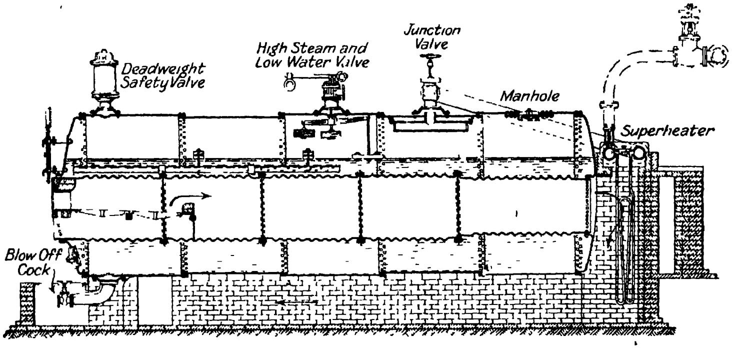

FIG. 161.—THE JOHN THOMPSON BOILER.

The special shape of the dished ends and the adoption of a long corrugated flue renders this boiler free from the usual troubles due to expansion.

Should any patches or caulking be necessary the work must be done in a proper manner. Disastrous explosions of steam boilers have repeatedly occurred shortly after repairs have been carried out, owing to these having been executed in an injudicious or defective manner. It is therefore important that special attention should be given to repairs in order to avoid any risk of disaster.

The whole of the defects should be considered so as to determine to what extent plates require renewal, patching, or other repairs. Thus, for instance, a plate may be seriously defective in one part, and there may be slight defects in another portion of it; if the worst part only be repaired, it is possible that the less serious defects may develop, and the plate may have to be renewed in a year or two. Under such circumstances it will often be advisable to renew the plate forthwith. Repairs must always be executed by first-class workmen under competent supervision. If a boiler is generally deteriorated, it is best to substitute another boiler for it rather than attempt to repair.

When repairs are in hand all the fractured, thinned, brittle, or otherwise defective plates should be entirely renewed. If the boiler is old, or the rivet holes in the plates adjacent to those removed be damaged by the removal of rivets or otherwise, the old line of rivet holes should be cut off and fresh holes made. The new plates should be carefully fitted to the proper curve or shape, in order to retain the shell or tube, or whatever part is under repair, in proper form.

Generally, the best quality of plates to use for ordinary repairs will be acid open hearth mild steel of a soft quality, such as that used for the furnaces of new boilers, say 24 to 28 tons ultimate tensile strength, with an elongation of not less than 23 per cent. in 8 inches.[1]

In repairing shell plates especially, care should be taken to avoid weakening the boiler by the adoption of a weaker riveted joint. The longitudinal seams should be arranged to break joint, and the riveting of them should be at least as strong as the original seams. Old rivets should always be drilled out where the plates are brittle, or where the rivet holes are suspected to be unfair, or the plate laps are scanty. This particularly applies to the longitudinal seams of boiler shells. Drilled rivet holes are the best. The " drift " should not be used to open out holes which are not fair, but the holes should be rimered out and larger rivets used to fill them. If all the holes are bad, the plate should be condemned in preference to spoiling the work.

Caulking should always be done by a qualified boilermaker. The dangers arising from the employment of unskilled labour are intensified when pneumatic tools are used, because the power is not limited like human power, and much damage can be done by a long-continued series of powerful strokes on a badly plated seam. The tool used, and the angle at which it is held, vary with the angle of the slanting edge of the plate. If the tool is held horizontally, not only will the edge of the plate swell up, but the lower plate will be scraped up, forming a small ridge. Fig. 162 shows a caulking tool in position for caulking a thick boiler plate.

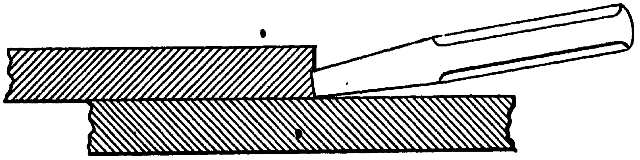

FIG. 162.—POSITION OF TOOL WHEN CAULKING THICK PLATES.

Where test holes are required to determine the depth of grooving or fracture in flanged end plates a special core drill may be used with advantage. Fig. 163 shows a drill made by the National Boiler Co., Ltd.

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[1] *Design, Construction, and Working of Vessels Subjected to Steam Pressure,* National Boiler and General Insurance Co., Ltd.

The core drill takes out a small core from the grooved or fractured part, and the core can then be closely examined to determine the depth of the defect, and the amount of sound metal remaining. The hole left by the core drill is suitable for tapping ½ inch gas thread to admit of a screwed plug being inserted.

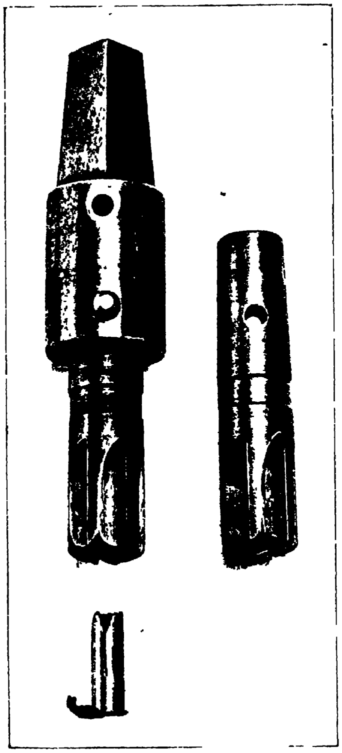
FIG. 163.—THE "NATIONAL" PATENT CORE DRILL

Fig. 164 illustrates grooving of a furnace flange of a Lancashire boiler (or in a flanged end plate), and shows how, by use of a core drill, the core containing the groove or furrow is left untouched, and proves the actual depth any fracture below the groove penetrates into the solid metal.

The internal fittings are (1) steam or antipriming pipe, (2) feed pipe, (3) high and low water alarm with floats, (4) scum troughs, (5) hangers with zinc plates; (6) patent circulating devices, (7) patent anticorrosive devices.

The steam and feed pipes should be examined for corrosion, and to see whether the supporting clamps and bolts are in good condition

The high and low water alarm floats, although protected by special treatment of the metal, are liable to corrode. If this occurs, water may find its way through a pin-hole, and the apparatus be thrown out of balance. When there is no water in the boiler the float ought to fall and lift the valve. If the float has become corroded it may lose its buoyancy or stick, and fail to shut the valve, although there is plenty of water in the boiler.

Scum pipes should be fitted with troughs or pans which can easily be renewed, as these corrode rapidly. If the pipe itself is corroded below water level it will serve only to draw off good water, which will enter at the point of corrosion to the exclusion of the scum which it is intended to carry away.

Many boilers are fitted with zinc slabs rigidly fixed to the stays by means of special hangers. It is absolutely essential that the hanger and stay should be polished perfectly bright, when the hanger is fitted, to ensure proper metallic contact. Fig. 165 shows a zinc hanger in position for a lower stay or between two furnaces or combustion chambers.

What really takes place is not known. There are several theories and a conflicting mass of practical evidence. Whatever the explanation, the zinc disappear more quickly than when subjected to electro-chemical disintegration elsewhere That the slabs have a very beneficial effect in retarding corrosion in boilers supplie with pure condensate has been proved, but their behaviour in other respects i uncertain. Suspended in various parts of a boiler, they sometimes turn black i colour, but retain their size; at other times they become covered with a hard scale and corrode very thin round the edges; in some positions they completely disappea If old slabs, cleaned free of scale, are simply thrown into the bottom of the boile they disappear by the time the boiler is again opened.

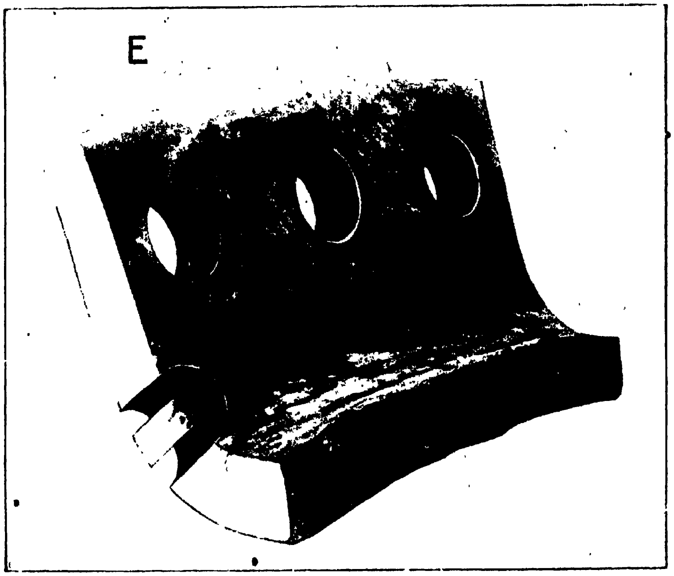

Fig. 164.—Grooving of a Lancashire Boiler Furnace Flange. The Core containing t Groove is left Untouched.

The remaining internal fittings consist of patent circulators and patent ant corrosion fittings, such as iron baskets, filled with metal, suspended in the upp part of a boiler, and connected by copper wires to steel studs fitted to the low parts. Their actions are obscure, and the wires are apt to be very inconvenie when working in a boiler.

Marine, locomotive, and vertical boilers are fitted with stays, and these must carefully examined every time the boiler is open.[1] Stays are of different sizes, a vary from the small screwed stay in a locomotive firebox, as fitted to wagons, the large bar stays of the marine boiler. Small screwed stays, as fitted to fireboxes of locomotive boilers, often corrode by grooving, or snap from brittleness and fatigue of the metal. The vibration to which the metal is subjected whilst under stress plays a considerable part in inducing fatigue. Fig. 166 shows examples of fractures in small screwed stays.

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[1] *A Manual of Locomotive Engineering*, W. F. Pettigrew.

When these stays break, a proportionate part of the plate remains unsupported, and the neighbouring stays have to take the extra load. If they are also corroded they may fail under the extra load. The unsupported plate bulges out, and if the stress is too great it tears, and the result is an explosion. The result of such an explosion is shown in fig. 167.

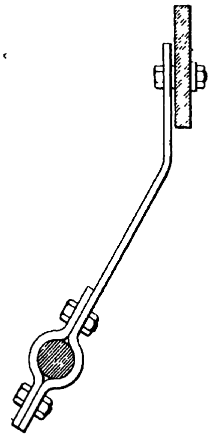

Fig. 165.—Zinc Hanger suitable for Clamping to the Stays of a Marine Boiler to prevent Corrosion of the Combustion Chamber Plates.

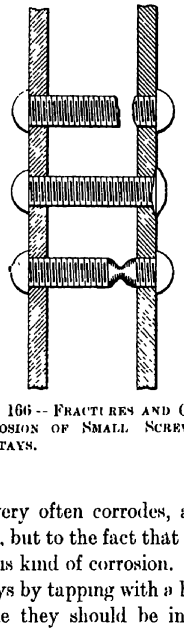

Fig 166.—Fractures and Corrosion of Small Screwed Stays.

In marine boilers the combustion chamber plate very often corrodes, and the extra stress on the plate is not due to the stays breaking, but to the fact that they no longer have a hold in the plate. Fig. 168 illustrates this kind of corrosion.

The usual method of examination is to sound the stays by tapping with a hammer and noting the "ring" of the metal. When possible they should be inspected visually or with the aid of a mirror. In some cases a hydraulic test will deflect the plate, and a distinct bulge is noticeable.

In view of the very high temperatures obtained in marine boilers working under forced draught, and especially in the case of oil-fired boilers, the nuts of all stays supporting the back combustion chamber plate must be suitably protected. Fig. 169 shows the Ægis stay nut protector made by Messrs. Christie and Dickinson.

The protector of fireclay or cast-iron has an inside thread corresponding to that of the iron ring shown in fig. 171. Without removing the stay nut a slot is cut in the nut as near as possible to the front (see fig. 170).

The helical iron ring forming a thread of ¾-inch pitch is hexagonal inside to fit over the nut; the protector is therefore mechanically fixed, and cannot shake off.

To support the front tube plate of a marine boiler some of the tubes are made thicker than the ordinary boiler tubes, and are screwed at the ends. These tubes are called stay tubes, and are generally twice the ordinary thickness.[1] In addition to being screwed into the front and back tube plates, the outside tubes are often fitted with a nut. The chief characteristic of these tubes is that both ends ar swelled, the front more than the back, to facilitate removal, and the thread mus be continuous, so that when the tube is being screwed into the front plate it als enters the back plate.

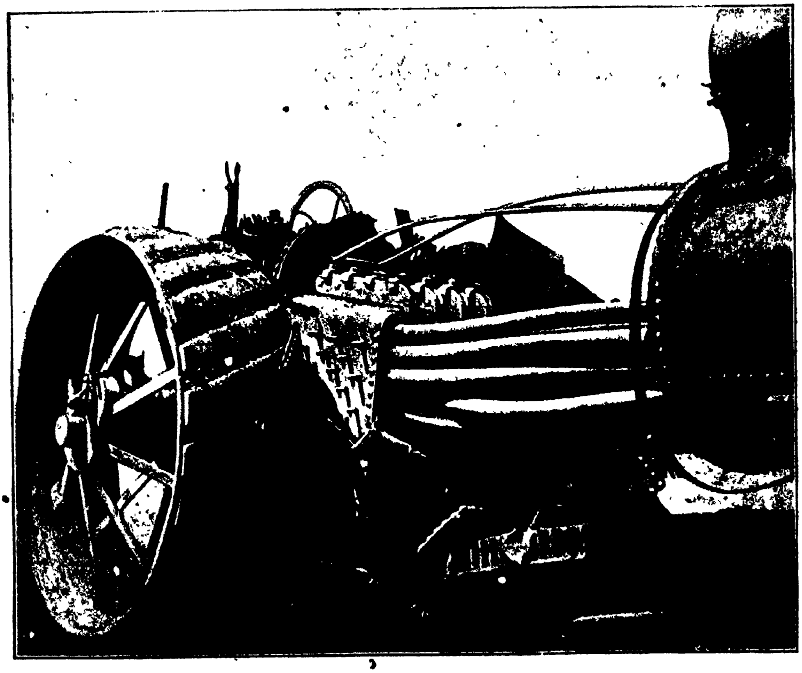

FIG. 167.—RESULT OF EXPLOSION OF LOCOMOTIVE TYPE BOILER OF A PLOUGHING ENGINE.

Lancashire boilers are fitted with plates situated radially and secured by angl irons to the shell and front or back plate. These plates are known as gusset stays Their function is to stiffen the end plates, and also to transmit the load on the en plate to the shell. All the rivets should be carefully inspected to ascertain that they are not loose, and the joint between the angle iron and shell or end plate should be examined for leakage.

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[1] "Mild Steel Tubes in Compression and Under Combined Stress," W. Mason, *Trans. Ins Mech. Eng.*, p. 1205, 1909.

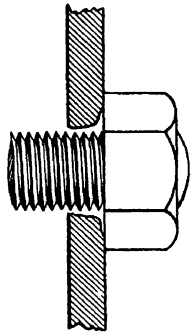

Fig. 168.—Corroded Combustion Chamber Plate.

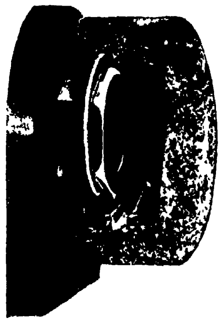

Fig. 169.—The "Aegis" Stay Nut Protector.

Boilers fitted with smoke tubes require special attention to make sure that none of the tubes are corroded. Marine boilers fitted with Howden's patent system of forced draught have spiral retarders in each tube, and these must, of course, be removed first in order to clean the tubes in a manner fit for an examination to be made. Deterioration generally takes place at the mouth of the tube, either at the back end, where excessive heat is the cause, or at the front end, where rapid change in temperature must be held responsible.

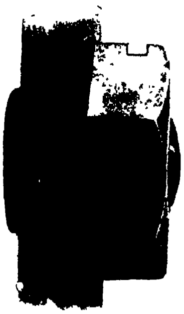

Fig. 170.—Slot cut in Stay Nut to receive Special Ring.

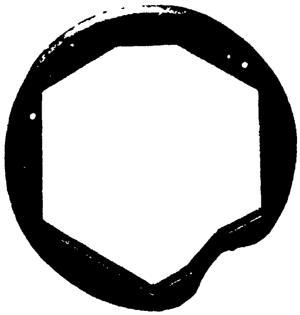

Fig. 171.—Helical Iron Ring forming the Thread shaped to fit over the Stay Nut.

In marine boilers worked under forced draught there is no possibility of air leaks like those experienced with boilers which are surrounded by leaky brickwork walls. Hence the former are subjected to very intense heat of combustion. The hot gases leaving the furnace enter the combustion chamber, and, sweeping upwards, return through the smoke tubes. If there is much scale round the necks of the lower tubes, both tube and tube plate will suffer from the intensity of the heat. To protect the tube ends, caps are often fitted, as shown in fig. 172. The front ends of the tubes generally suffer from rapidly alternating temperatures.

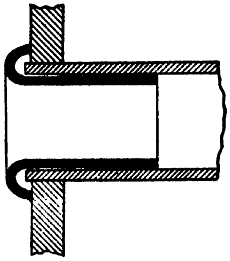
FIG. 172.—CAP TO PROTECT TUBE END FROM BECOMING BURNT.

It is a common practice to open the smoke-box doors in order to deprive the boiler of all draught, and thus to cool it rapidly, so that tube cleaning may commence with as little loss of time as possible. Cold air rushes into the smoke-box, and the comparatively thin metal of the tubes ($\frac{3}{16}$ inch thick) contracts very much more quickly than the thick tube plate (about $1\frac{1}{4}$ inch thick). The result is that the tubes leak and are re-expanded, and the metal is unnecessarily stressed.

Leaky tubes in some cases may also be attributed to accumulation of scale between the tubes. As it is a tedious and difficult proceeding to clean all the boiler tubes, the work is often performed unsatisfactorily, but if a boiler is properly looked after, no such scale will collect.

When a tube leaks a tube stopper is used. Fig. 173 shows an ordinary tube stopper, consisting of two blind flanges placed at either end of the tube and connected by a long bolt.

To install this a man must, of course, get into the combustion chamber or " back end " for the purpose of putting the blind flange on to the bolt and screwing up the nut where it projects beyond the back tube plate. Although this unpleasant task has been performed thousands of times by pushing a man on a plank into the furnace whilst the boiler has been in operation, and drawing him out after a couple of minutes to let another man " have a spell," the work, even though necessary to keep things going, can only be described as " hellish." To avoid the necessity of such performances, patent tube stoppers were introduced, and these consist of two cones of soft metal held between plates screwed on to a long rod. Between the two pieces of metal, and acting as a ferrule, is a long pipe, through which the rod passes. By holding the pipe—that is, the distance piece—and screwing up the rod, the soft metal is compressed and blocks the tube at the front and back ends, imprisoning the water.

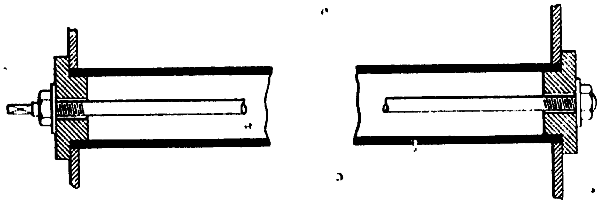
FIG. 173.—AN ORDINARY TUBE STOPPER FOR BLOCKING OFF LEAKY TUBE.

As soon as possible the leaky tube must be taken out, and a new one inserted, because the screwed rod has sometimes failed as a result of excessive tensile stress. The boiler pressure tends to force the two metal cones apart, and one end has been blown clean through the smoke-box door.

If a tube leaks, and this is not stopped, the tube plate will start corroding, as shown in fig. 174.

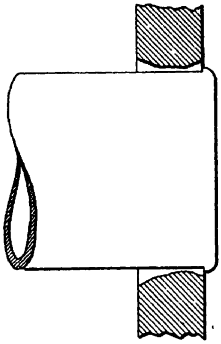

FIG. 174.—CORRODED TUBE PLATE.

(*c*) *Parts Subjected to High Temperatures.*—In the cylindrical boiler it is the furnace that is subjected to the highest temperatures; in water-tube boilers it is the front rows of tubes, and in locomotive boilers it is the firebox. These parts require special attention on account of the very severe conditions under which they work.

Furnaces may be plain or corrugated, but in all cases they must be tested with the view of ascertaining whether they have lost their true circular shape. If three plain centre punch marks be made in the lower half of a furnace, one end of a telescope gauge can be inserted into one of them, and the other end adjusted by working to the right and left and backwards and forwards until the maximum diameter is found. The three punch marks should be made so that the gauge will be vertical, 30° to the right, and 30° to the left, as shown by the full and dotted lines in fig. 175.

An ordinary gauge made in the workshop may be used; but the illustration shows the patent "Clyde" gauge made by Messrs. Dobbie, McInnes and Clyde, Ltd., which is fitted with a special indicator, whereby the deflection of the furnace is read on a brass plate without any trouble. Along the furnace a series of points should be marked an equal distance from one another, and if furnaces are gauged every six months and the results tabulated, the behaviour of a furnace is known.

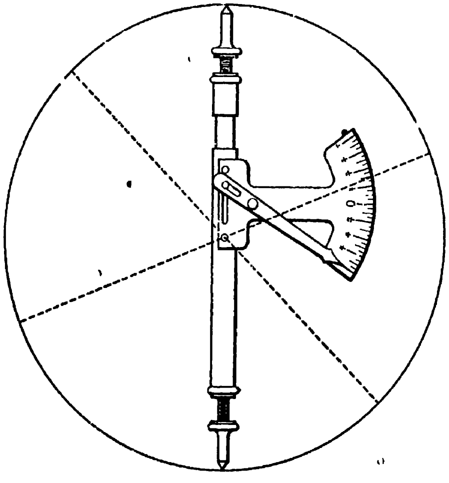

FIG. 175.—THE CLYDE GAUGE FOR MEASURING FURNACE DEFLECTION.

Outside, the furnace should be examined to see that it is free of all scale and grease. Due to the high temperature on the fire side of the plate the transmission of heat through the plate must be very rapid, and that means that the water must absorb this heat immediately; otherwise the furnace will collapse. In order that the water may absorb the heat rapidly, the steam which is constantly being formed must leave the hot plates quickly, and this will not be the case if the plates are covered with scale or a film of grease. The effect of scale is shown in fig. 176.

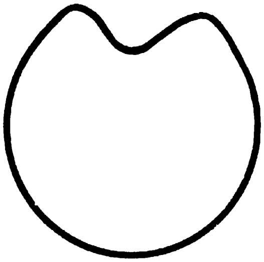

FIG. 176.—FURNACE DEFORMED, DUE TO A DEPOSIT OF SCALE.

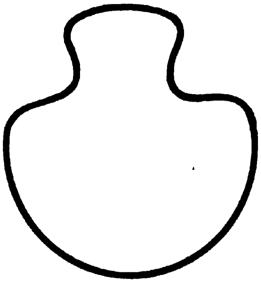

FIG. 177.—FURNACE DEFORMED, DUE TO A DEPOSIT OF GREASE.

Mr. E. G. Hiller, in his book *Working of Steam Boilers*, when describing the effect of feed water contaminated with oil or grease with or without an admixture of deposit, says:

"Under such circumstances two actions would appear to take place—the oil or grease apparently forms a non-conducting film round the furnace, and the mixture of the oily matter and deposit in the water thickens the water, increasing the resistance to the escape of steam. These actions result in the formation of a more or less continuous layer of steam round the furnace, checking the transmission of heat, causing the bulging in of the furnace sides and the crown."

Fig. 177 illustrates this phenomenon.

In order to prevent accidents from the overheating of furnaces when the water becomes low, fusible plugs are often fitted in the crown near the back end of the grate (see fig. 33). These fusible plugs should be properly cleaned at the same time as the boiler. If this is not done, a thick scale will form on the water-side of the plug, and an accumulation of hard deposit will be found on the fire-side. Fig. 178 shows a fusible plug which has been neglected.

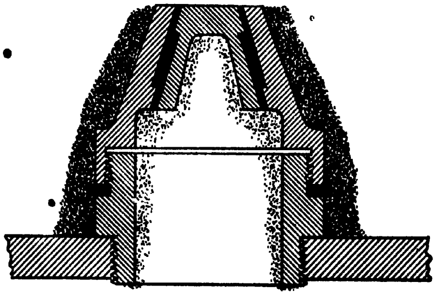

FIG. 178.—NEGLECTED FUSIBLE PLUG.

A plug in this condition would probably become overheated when there was no shortage of water. After studying the exact requirements which must be fulfilled to secure efficiency, the National

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[1] *Working of Steam Boilers*, E. G. Hiller.

Boiler Insurance Co., Ltd., have patented a series of fusible plugs which give excellent results in practice. They have undoubtedly saved many a delicate situation from developing into a disaster.

The metal along the level of the firebars needs careful examination for signs of wasting such as are shown in fig. 179.

The flues of Lancashire boilers are generally fitted with expansion hoops, as a substitute for corrugations in the furnace, to allow for the expansion and contraction of the flue. These hoops are very liable to become pitted. If a flue shows any signs of corrosion it must be extra carefully watched. Patching a flue is at best a makeshift, and welding is very undesirable. Where the trouble is at all serious, good practice calls for the fitting of a new flue. Should it be decided, however, for some reason or other to repair the flue tubes special consideration must be given to the question of compensating for any weakening of the tube which may be caused by the removal of strengthening hoops, flanged seams or cross-water tubes. Flue tubes of the flanged seam type are frequently of adequate strength without cross tubes, but the removal of cross tubes from plain furnaces weakens them seriously, and has resulted in collapse. On no account should the water tubes be dispensed with in Galloway and similar types of flue tubes, as these depend for their strength on the cross tubes, and are dangerously weakened if they are removed. Extensive grooves in the roots of furnace or flue tube flanged seams generally necessitate repair by cut-out flanged patches applied on the water-side, the defective parts being cut out to avoid a double thickness of plate and to obtain external caulking edges.

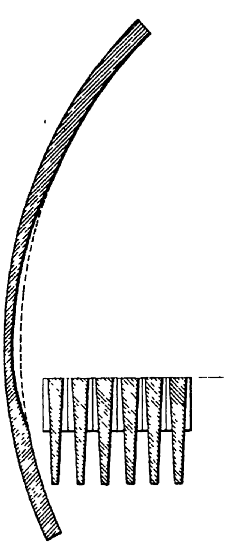

FIG. 179.—CORROSION ALONG THE LINE OF THE FIREBARS.

In connection with the fitting of new flues it may be of interest to recall that the fronts of furnaces fitted to marine boilers are circular and the backs are pear-shaped, with the bottom radius less than that at the front end. When a furnace has been pulled out a certain distance it is lifted at the front. If properly slung it can easily be withdrawn from the boiler. Flues or furnaces which are shown, by the results obtained when gauging, to be slightly out of shape may be reshaped by the judicious use of packing and a screw-jack. The work must be done very carefully, and if it is only the crown that has collapsed slightly, it is essential to provide proper support between the bottom of the flue and the boiler shell.

Furnace flanges often develop severe grooving. The metal in this case is furrowed with narrow V grooves, which in course of time become fine cracks. Two distinct types of grooving are shown in fig. 180.

The depth of cracks may often be determined by drilling a small hole, examining the interior, and then fitting a tight stud neatly. It is essential that the surface should be filed perfectly smooth after completion of the job.

Oil is largely used as a fuel on board ship, and this has changed the conditions under which furnaces in marine boilers are operated. The lower half of a coal-fired furnace serves the purpose of an ashpit, and the quantity of heat transmitted downwards through it is at the best of times comparatively small. As soon as the fires get low, circulation stops altogether, and large pockets of cold water collect. With oil fuel there are no firebars, and the whole of the furnace is efficient heating surface. Consequently a risk of scale depositing in the very narrow space between the underside of the furnace and the boiler shell is increased.

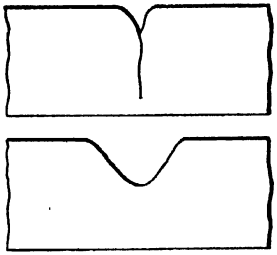

FIG. 180.—GROOVING.

In water-tube boilers the tubes nearest the furnace do as much work as all the remainder, and are particularly liable to acquire a deposit of scale-forming matter, if the feed water is not pure, by reason of the intense heat to which they are subject.

Tubes may also develop serious bulges as a result of overheating, due to bad circulation of the water. Grease and oil are the greatest enemies of the water-tube boiler, and the thinnest film will cause the burning-out of a tube in a short time. When new boilers are erected it is of the greatest importance to see that all grease that may have been applied to any part to prevent rusting is thoroughly removed. In the multiple drum type of water-tube boiler which has curved tubes, such as the Stirling boiler, sediment often collects in the bends, as shown in fig. 181.

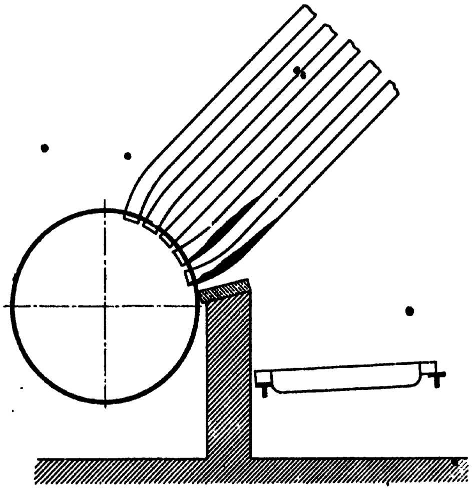

FIG. 181.—COLLECTION OF SEDIMENT IN THE CURVED TUBES OF A WATER-TUBE BOILER.

In making a proper examination of water-tube boilers of the header type, such as the Babcock and Wilcox boiler, the initial procedure is the same as in the case of a Lancashire boiler. The following additional preparations must be undertaken:

All the caps at both ends of the tubes should be taken off, and the tubes and headers thoroughly cleaned of deposit. The mud drums should be opened and cleaned. It is recommended that the mud drums be bared of brickwork at each internal and external inspection. For internal and external inspection, and at each cleaning time, the cleaner should be passed through every tube, and special care should be taken to ensure that there is a clear " full bore " waterway through every tube, particularly in the case of curved tube boilers. Great danger of explosion is incurred if this precaution is neglected. The flues should be made accessible at all parts, and soot removed. The water tubes and the plates of the steam and water drums should be well brushed. Any damp brickwork or damp top covering should be taken up for the examination of the plates beneath. Some boilers have inner circulating tubes, as, for instance, the Niclausse boiler, and in such cases these should be removed. When any tubes are renewed opportunity should be taken to examine the thickness of the header. When examining the nipples connecting the headers to the steam drum it should be remembered that the nipples carry the whole weight of the tube elements.

In water-tube boilers the tubes of which are expanded into front and back headers the lower tubes sometimes suffer from the peculiar phenomenon known as " hogging." The boiler tubes are distorted to an arc of a large radius, but the deflection is upwards instead of downwards. This is due to the intense heat to which the tubes are subjected when the boiler is working. As a general rule, this condition occurs when the feed water is impure or the boiler has been overloaded for a long time. When all the caps are off, the engineer-chemist must himself look through every tube, whilst an assistant holds a lamp at the other end.

It is a good plan to withdraw at least one tube at each inspection and to cut it through for the purpose of ascertaining the exact thickness of the deposit. Unless one is constantly engaged in such work, a slight rise in the centre, denoting an increase in the thickness of scale, will escape the eye. The tubes sometimes develop blisters, generally on the outside. A small bubble of air or gas remains imprisoned when the tubes are rolled, and later, when overheating occurs, the gas expands, forcing the metal outwards. The origin and development of such a blister are shown in fig. 182.

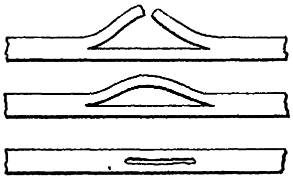

FIG. 182.—DEVELOPMENT OF A BLISTER

As already stated, the caps should be carefully cleaned, and, before replacing, each cap, clamp, and bolt should be examined for fractures or wear. Where a cover joint leaks it may be an indication of either a defective bolt or clamp. The joints themselves must be inspected to see that they are in perfect condition. Should any of the joints leak and not " take up " when the boiler is restarted, no remedy is possible except by adopting the extremely dangerous course of applying force to tighten up while the boiler is under pressure. Quite apart from the risk incurred by the attendant, the likelihood of obtaining a satisfactory result from this measure of desperation is quite remote.

The front and back headers also require examination for signs of pitting and cracks. If any tubes are renewed the holes into which the tubes are expanded should be truly circular, and should be carefully cleaned out before the tubes are expanded into them. The rough scale on the tube itself should also be removed. Expanding should be carried out without unduly stressing the tube or causing local cracking of the plate into which the tube is expanded, and the projecting part of the tube should be bell-mouthed to safeguard against drawing out. It may be said that bell-mouthing is particularly important in those cases where the tubes are curved, as in the case of multiple drum type water-tube boilers. The tubes should be sufficiently ductile to stand such expanding and bell-mouthing without splitting or showing other flaws. If tubes are welded the welds should be turned away from the direction of the flow of the hottest gases. In order that the bell-mouthing may be properly done, the tube should project beyond the plate into which it is expanded, from $\frac{1}{4}$ to $\frac{1}{2}$ inch. When finished the bell-mouthed end of the tube should be about $\frac{1}{8}$ inch greater in external diameter than the hole in the plate into which it is expanded.

Water-tube boilers are often fitted with steam blowers for removing soot from the outside of the tubes. As long as these are only used when the boiler is in operation no steam will condense on the tubes. Often, however, when the boiler is not at work, steam is used for cleaning the tubes by coupling a flexible hose to a convenient source of supply. In this case the steam will condense on the tubes and commence external corrosion.

Tubes also corrode, due to "sweating," when cold feed water is used. If coal containing a large percentage of sulphur is burnt they are liable to waste away.

The subject of boiler corrosion is in itself a most fascinating one, as the author can testify from long years of personal research. Space does not permit of more than a brief general notice of the importance of the topic.[1] [2] Every case of corrosion trouble must be treated on its own merits according to an expert diagnosis of the disease. Among the main causes of corrosion are: (1) dampness; (2) gases dissolved in the feed water; (3) gases naturally present; (4) atmospheric oxidation (rusting); (5) acids; (6) mineral constituents; (7) ammonia; (8) electro-chemical action; (9) leakage from surface condensers.

An example of a corroded front plate is shown in fig. 183.

The metal may show signs of pitting, channelling, grooving, cracking, wasting, honeycombing, all of which can be present in different varieties. The practical man treats the trouble according to the symptoms present, and does not busy himself with scientific investigations such as would be expected from the engineer-chemist. Figs. 184, 185, and 186 illustrate these defects and indicate where they will be found in Lancashire, water-tube, and vertical boilers respectively. These illustrations and fig. 223 in Chapter XIX have been prepared from original drawings kindly lent by Sir Isaac Pitman and Sons, Ltd., publishers of Mr. R. Clayton's very excellent book, *Boiler Inspection and Maintenance*, in which they were first used.

Boilers which are fed with pure distilled water may be protected from corrosion by allowing a very thin scale, about $\frac{1}{64}$ inch or less, to cover the immersed parts and by keeping the feed water slightly alkaline. For this purpose about 3 pounds of lime and 10 pounds of ordinary washing soda may be thrown into the boiler afte it has been thoroughly washed out and is ready for closing up. The quantity mentioned is sufficient for a boiler which evaporates 15,000 pounds of water pe hour, and which is opened every three months for inspection.

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[1] "Explosion of a Stirling Boiler," *Engineering*, vol. 190, p. 115.

[2] "Boiler Explosion at Dudley," W. Smith, *Trans. Mech. Eng.*, June, 1848.

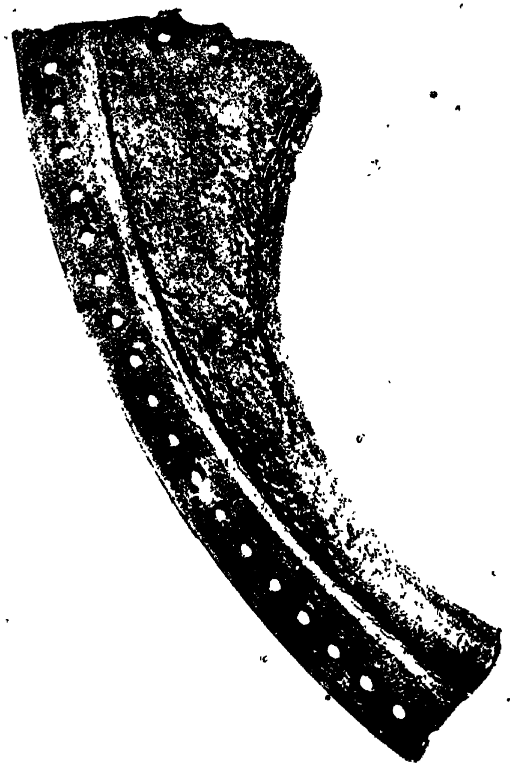


Fig. 183.—Grooved Front End Plate.

The inside of the boiler above the water level should be painted with a ver thin wash of white zinc and kerosene oil, but the preparation of the paint shoul be personally supervised by the engineer-chemist to ensure that it shall contai no vegetable oils, such as boiled oil or linseed oil.

Before closing up the boiler the engineer-chemist should examine the inside t

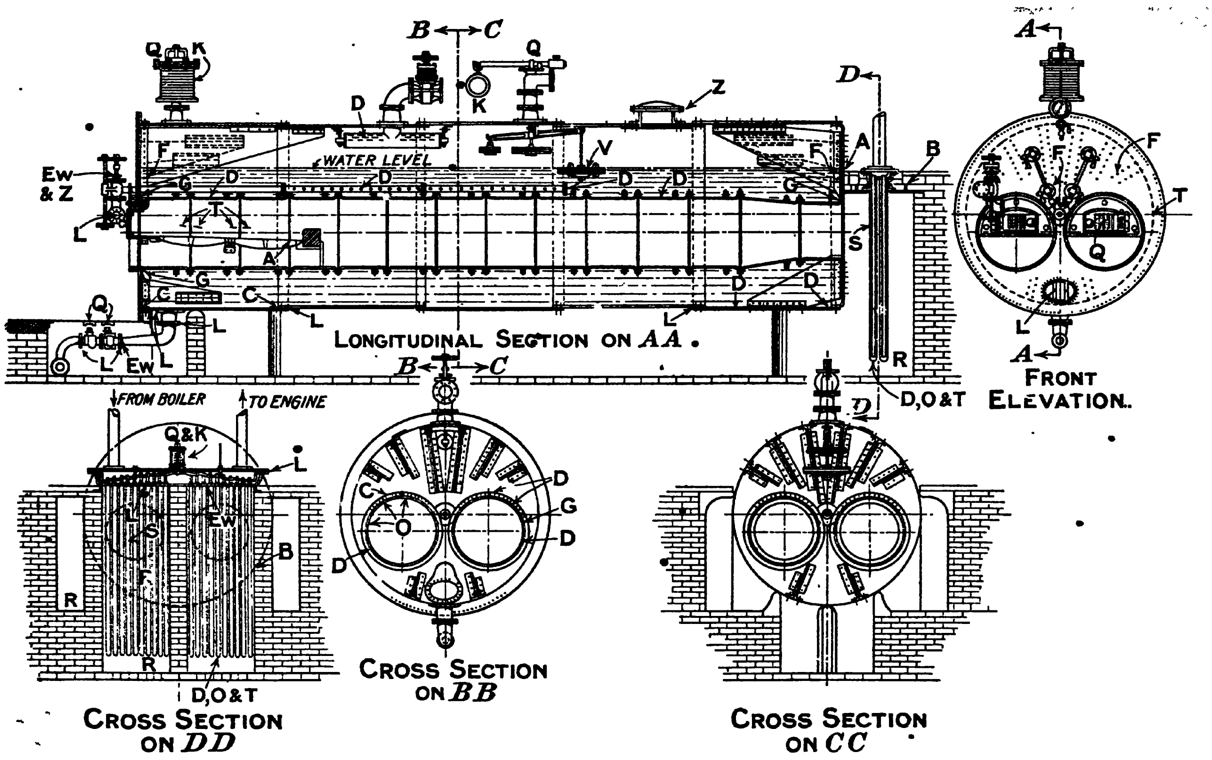


FIG. 184.—MODERN HIGH PRESSURE LANCASHIRE BOILER WITH BOLTON SUPERHEATER.

A = Air Leakage.
B = Cracked or Broken Brickwork.
C = Channelling.
D = Deposit on Water Side.
Ew = External Wasting.
F = Fracture.

G = Grooving.
K = Overloading.
L = Leakage at Seams.
O = Overheating of Plates.
Q = Rust and Deposit causing Sticking.

R = External Deposit of Flue Dust.
S = Splitting of Tubes and Tube Ends.
T = Cracks.
V = Breaking of "Float."
Z = Wearing of Screw Threads.

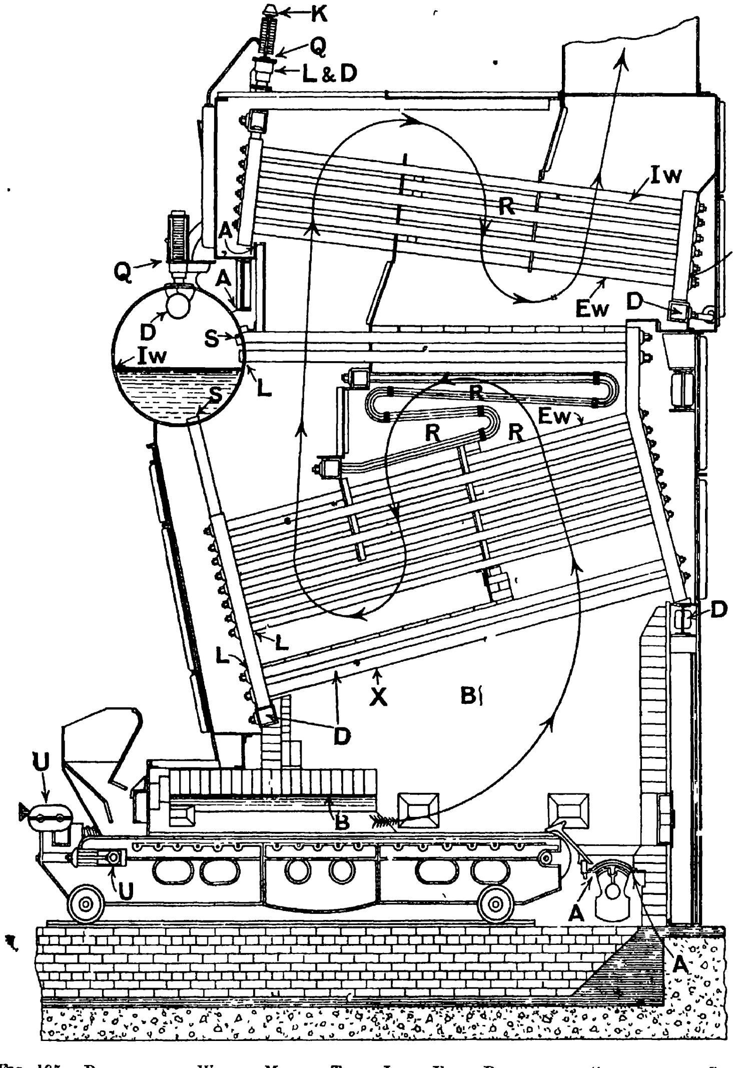
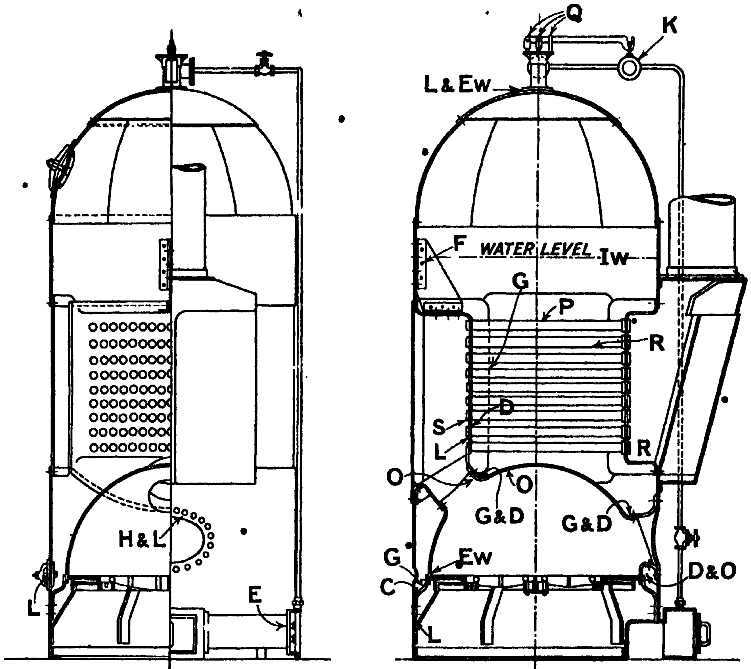


Fig. 185.—Babcock and Wilcox Marine Type, Land Form Boiler with Superheater, Superimposed Economizer, and Chain Grate Stoker.

A = Air Leakage.
B = Cracked or Broken Brickwork.
D = Deposit on Water Side.
Ew = External Wasting.
Iw = Internal Wasting.
K = Overloading.

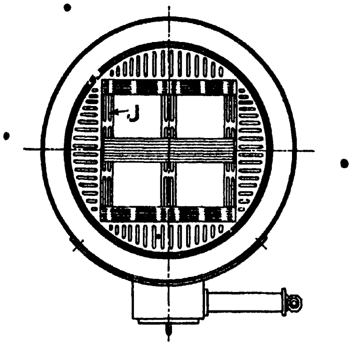
L = Leakage.
Q = Rust and Deposit causing Sticking.
R = External Deposit of Flue Dust.
S = Splitting of Tubes and Tube Ends.
U = Lack of Lubricant.
X = Hogging and Bulging.



HALF SECTIONAL ELEVATION.

FRONT ELEVATION.

SECTIONAL ELEVATION.



SECTIONAL PLAN ON GRATE.

FIG. 186.—COCHRAN BOILER WITH MELDRUM STEAM JET FURNACE.

C = Channelling.
D = Deposit on Water Side.
E = Erosion of Jets and High Steam Consumption.
Ew = External Wasting.
F = Fracture.
G = Grooving.
H = Lap Cracks.
Iw = Internal Wasting.

J = Burning of Firebars and Loss of Fuel.
K = Overloading.
L = Leakage at Seams.
O = Overheating of Plates.
P = Pitting.
Q = Rust and Deposit causing Sticking.
R = External Deposit of Flue Dust.
S = Splitting of Tubes and Tube Ends.

make sure that all the necessary work has been done in a satisfactory manner, that no tools or bags have been left inside the boiler—in particular on top of the furnace or flue; and that all bags, etc., which may have been stuffed into stop-valve or other openings to prevent drops of hot water falling on the men whilst they were working in the vicinity of a leaky valve, have been removed.

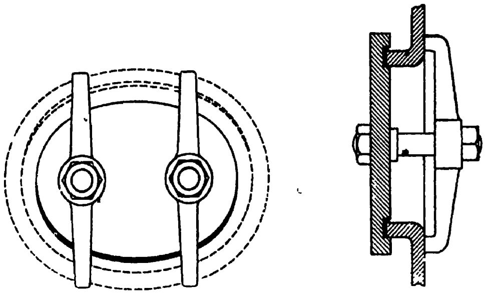


FIG. 187.—FAULTY MANHOLE COVER JOINT GIVING EXCESSIVE CLEARANCE.

He should also supervise the replacing of the manhole covers, as this is a task requiring great care. Many bad accidents have happened because joints were badly made. Fig. 187 shows a manhole cover spigot which is too large.

When the cover is in position the clearance all round should be carefully tested, and an old table knife inserted between the boiler flange and the recess in the cover serves well for this purpose.

12 OCT 1925

CHAPTER XVI

EXTERNAL INSPECTION

(*a*) *Boiler Covering.*—The covering of boilers varies very considerably, whether they are in the open air, as shown in fig. 46, or properly housed and protected from the weather. Magnesia, asbestos, fossil meal, slag wool, hair felt, mica, various cements, and a host of patent coverings containing some of the above substances in varying proportions are the materials most commonly used.

In view of the fact that the lagging must be removed from the shell of a boiler once a year to provide for a proper examination of the plates, the covering should either be in the form of removable segments or be a composition of such a character that it can be used again. Removable insulating material may be in receptacles, such as a mattress made of good asbestos cloth and filled with asbestos or slag wool. For this purpose canvas is useless, because it will rot under the influence of heat. Asbestos cloth mattresses are suitable for the tops of economizers, over manhole covers, and (in a small size provided with stout hooks and eyes) for placing round flanges, valves, etc. On the other hand, hard durable slabs may be used for covering boiler tops, and softer and much lighter blocks, generally made of magnesia, applied to the sides.

In open-air plants the boiler shell is generally covered with a soft brown compound containing a large percentage of nondescript matter, protected by a layer of bricks. If the bricks, which are placed radially with the boiler, are in good bond, and rain and leaks have not washed away all the cement between them, this covering will serve for outdoor work, but its efficiency is low. Some open-air plants are covered with composition only. This is easy to work, and gives a neat appearance when newly applied, but it soon becomes porous. Water soaks into it, and it then becomes sodden after a heavy rain shower. When the heat of the boiler dries the composition, clouds of steam arise. This is bad for the boilers, but the effect on the lagging is worse, because after several rebakings it forms into solid lumps which detach themselves from the boiler, allowing rain and water from leaks to run at will over the whole shell of the boiler. Every time a boiler thus covered is inspected the entire shell must be very scrupulously cleaned, and painted with two thick coats of iron oxide and boiled oil. Fig. 188 shows an example of grooving adjacent to a seam and wasting over a general area.

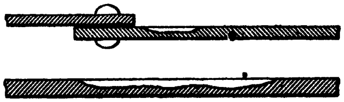


FIG. 188.—EXAMPLES OF CORROSION.

For indoor work a good plastic composition, containing at least 85 per cent.

magnesia, may well be adopted. Sometimes the layout is such that attendants require constantly to climb over the tops of the boilers to reach valves or for some similar purpose. Wherever this is the case the lagging must be protected by steel sheets or a special platform must be fitted.

That all parts which radiate heat should be covered need hardly be stated, but that the covering should be well chosen, of good quality, and so made that it can be removed when necessary, is not always realized. The argument often employed is that as the covering has to be removed it need not be of expensive material.

It has already been mentioned that covering should be removable or of such a nature that it can be used again. Ordinary composition cannot be used again with any measure of success, but magnesia composition can be pounded up and used over and over again.

Indoor plants covered with ordinary composition should be painted with two thick coats of good black paint or one coat of tar. This gives the covering a shiny black finish, and greatly facilitates keeping the boiler tops clean.

When boilers are being covered with composition the work should be performed slowly, especially at first, so that the material may bind properly with the steel plate. Unless this precaution is taken, the composition will become detached *en masse*.

In order to make a proper examination of the shell, all lagging must be removed, side flue covers, or brickwork over the flues, and front wall bricks round the boiler must be taken out, and all seating blocks that obstruct inspection of the circular seams must be shifted. Fig. 189 shows an example of close isolated pitting such as often is found under damp brickwork.

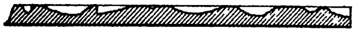


FIG. 189.—CLOSE ISOLATED PITTING

(*b*) *Boiler Mountings.*—Boiler mountings may be divided into two sections—viz., steam fittings and water fittings. Under the description of steam fittings may be listed the following: main boiler stop-valve, auxiliary boiler stop-valve (if there are two separate ranges), spring-loaded safety-valve and dead-weight safety-valve; high and low water alarm; steam pressure gauge; and any small valves or cocks for supplying steam direct to a feed pump, to steam jets, to soot blowers, to recording instruments, etc.

The water fittings will be represented by a main and (if two independent ranges are in use) an auxiliary feed-check valve; water gauge glass; blow-down valve or cock; scum valve; salinometer cock, and such small cocks or valves as may be connected to the shell direct.

There are a large number of firms of repute engaged in the manufacture of boiler fittings and, as already mentioned in an earlier section dealing with scientific instruments, these manufacturers are responsible for publications which would grace any library and which may advantageously be consulted by readers desiring to study the concrete application of the general principles dealt with in the present work.

First we will consider the steam fittings.

The main stop-valve must be of sound design and construction. The cover and body should be of cast steel, but the seat and the valve itself of some special alloy suitable for the temperature of the steam. The valve should be fitted with an expansion spindle, which will eliminate the danger of bending or breaking and thus distorting the threads or jamming the valve. Such distortion and jamming are liable to occur when a solid spindle is used. The unequal expansion of the solid spindle and the valve body creates stresses sufficient at times to fracture the body and cover. The valve must be attached to the spindle, and the spindle must be perfectly controlled by a guide on the cover. In other words, the spindle must be of the external screw pattern. Preferably the stop-valve should be fitted with a separate handle by which the valve itself may be rotated on its seat so as to find a fresh bearing.

The valve seat should be securelv fixed by set screws passing through the body of the valve, so that there may be no chance of the valve seat becoming slack and lifting with the valve. The valve must be designed so that the steam pressure will always be underneath the valve. In that case, even should it become detached, the valve may still be worked as a screw-down non-return (check) valve, for the steam pressure will lift it and the screw spindle will close it.

Boiler stop-valve explosions have become very frequent in recent years. Modern conditions of high temperature and high pressure place a very much severer strain upon these valves than that to which they were subjected under old-fashioned methods of steam raising; and it is only beginning to be realized that constant attention is now required to guard against valve trouble.

What has been said regarding main stop-valves applies also to auxiliary stop-valves.

Spring-loaded safety-valves should be of ample size, and designed in such a manner that the spring may be protected from dirt, moisture, and other corrosion-producing conditions. They must be so constructed that the covers may be locked. When the valve has been adjusted it is essential that no unauthorized person should be able to interfere with the setting. The springs should be of square section steel, and should rest on extra strong plates. If they are allowed to exert a pressure direct on the valve the latter is liable to become distorted and crack. The safety-ve body should be fitted with a drain to avoid water-hammer, and the waste am pipe should have as few bends as possible. When the safety-valve is fitted the boiler in such a position that, should it lift, there is no risk whatever of anyone ceiving scalds from its discharge, there is something to be said for the omission of he waste steam pipe, but only in cases where the pipe, if fitted, would of necessity be tortuous. If the waste steam pipe discharges upward the end should be slightly bent, but not through a right angle. If this precaution be neglected dirt will fall into the pipe and eventually find its way under the valve when the latter lifts. Steam will then escape. This is generally what has happened when safety-valves commence "weeping."

Dead-weight safety-valves should have the weights enclosed in a lock-up case. With this type of valve it is most important that no moisture should corrode the weights, and that no dirt should find its way into the valve. Neglect of these precautions may cause the valve to stick at a critical moment.

The valve should be pendulously weighted, the preponderance of weights being below the valve seat to make sure of a perfect balance. The discharging capacity must increase steadily as the pressure rises. There must be no "jumping" or tilting of the valve on its seat, which might cause priming.

This type of valve should be fitted with a pipe to convey the discharged steam away, so that there may be no risk of scalding. Of course, the pipe should not be tortuous, as in that case condensed steam will collect and very bad water hammer may result. It is through the discharge pipe (because this is usually short and discharges upward) that dirt finds its way into the interior of the valve, and although it is most important that this pipe should be kept clear, it is frequently neglected. The steam leaves at a high level and right under the outer casing of the valve casting, whilst in the spring-loaded type the valve is almost on a level with the discharge opening

When the boiler is being cleaned the component parts of the valves should be taken to the repair shop and thoroughly overhauled. The springs or weights (as the case may be), covers, and bodies should be painted with two coats of good red lead and boiled oil.

High and low water alarms are only fitted to land boilers, particularly to Lancashire boilers. The apparatus consists of a float attached to one end of a lever.

The lever is suspended by a pin passing through a fork screwed into the boiler shell. This fulcrum and the float are on the same half of the lever, the fulcrum being 3 inches from the centre. The other end of the lever is loaded with weights. The centre of the lever is provided with a knife edge which raises a vertical spindle, also weighted, with valve attached. When the water is either too high or too low, the attention of the fireman is aroused by the sound of escaping steam, or by a whistle, if this is fitted. The float is generally made of steel specially treated to resist corrosion, but the weights on the lever and the valve spindle should be thoroughly examined and, when clean, properly painted with white lead and kerosene oil. Under no circumstances whatsoever must paint containing vegetable oil be used.

With proper cleaning and overhauling this apparatus need give no trouble, but in actual practice it is very frequently in a bad state of repair.

With the high and low water alarm is often incorporated a lever-loaded safety-valve. Formerly lever-loaded safety-valves were embodied in the design of boiler stop-valves, but such fittings are very bad design indeed. The boilers involved in the famous Distington explosion of September 18, 1909, were all fitted with this primitive device. In other respects they were in good order, and the general working conditions were quite satisfactory, but owing to the failure of the safety-valve to indicate what was happening, the pressure accumulated until it was sufficient to explode four boilers and cause widespread destruction of surrounding machinery. Two enquiries were held—one by the Board of Trade, and the other by the National Boiler and General Insurance Company. The lesson drawn from the disaster was that such an arrangement as is here condemned should never be adopted.

Perhaps the most important fitting on a boiler is the steam pressure gauge. At any rate, it is entitled to share the position of honour with the gauge glass. Yet both of these fittings are often allowed to get into a shocking state of disrepair. Pressure gauges which do not register correctly are as common as flies. On many boilers they are small fittings, and so dirty that it is hard to read the figures on the dial. Some gauges never fall below 30 pounds pressure when the boiler is cold, whilst the majority are incapable of recording less than 5 pounds per square inch-pressure.

Water-tube boilers are fitted with pressure gauges having large dials. Being fitted high above the floor level, they could not be read easily if the dials were small. The gauges fitted to Lancashire boilers are frequently ridiculously small, and although more accessible, are liable, if not frequently cleaned, to acquire coatings of grime from their nearness to the furnace. Pressure gauges should be tested regularly and, if unsatisfactory, should be returned to the makers for repair. The adjusting required may not be particularly intricate, but the instrument is too important to justify taking the risk of allowing anyone to repair it, who has not specialized in work of that character. If a pressure gauge is to all appearances in good working order it need only be tested in the workshop by coupling it to a pressure gauge tester made by a manufacturer of repute, and by comparing the readings of the two instruments.

A graph should be drawn by plotting the pressures as indicated on the gauge being tested and the value of the actual pressure applied. If the points be on a straight line then the pressure gauge has a constant error, the extent of which is given by the point where the straight line cuts the ordinate. Such a case is illustrated in fig. 190.

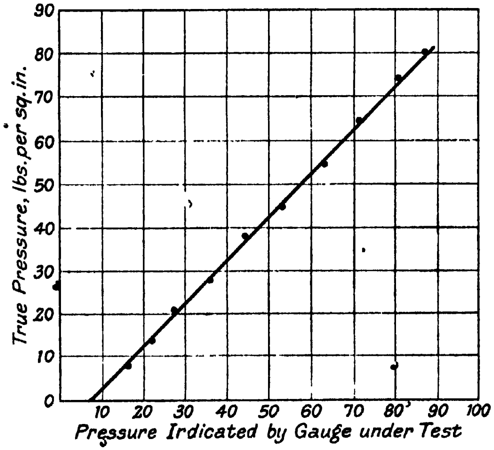


FIG. 190.—PRESSURE GAUGE CALIBRATION DIAGRAM.

The gauge can safely be used, as the actual pressure is known to be so many pounds above or below that shown on the dial. If the points do not lie on a straight line the gauge is erratic and must be replaced by a new one.

Pressure gauges should not be connected direct to the boiler, but a small U syphon should be interposed to permit of the transmission of the pressure through a column of water, by which means steam is prevented from having direct access to the gauge. The gauge should, however, be as near to the boiler as possible, and the syphon should be fitted with an extra connection tapped to take an inspector's pressure gauge.

Double pressure gauges, which are fitted with two pointers which rotate in opposite directions, are misleading, and should not be adopted for general use.

Each boiler should, of course, have its own pressure gauge graduated to read 25 per cent. higher than the blow-off pressure of the boiler.

When the internal boiler inspection is being made, the bore of the pressure gauge connection should be examined, and when the boiler is at work the small drain should be opened once a week to make sure that there is a clear passage.

Small valves and cocks need give very little trouble. It is, however, a common mistake to suppose that, being small, their quality is of little importance. In practice small fittings of the " cheap and nasty " sort are a continual source of annoyance, and even a danger to life.

Cocks are often screwed into the shell, instead of being fitted with a flange and secured by at least three ¾-inch diameter studs. As cocks not infrequently stick, undue leverage is applied by using a short length of pipe, and the handle comes off. Nothing can be done to remedy the defect thus created until the boiler is again shut down for cleaning. All cocks fitted direct to a boiler should be of special design, and the slots in the body of the cock should be packed with special fine asbestos.

Small valves, unless of good, heavy, sound construction, are a constant source of trouble, always leaking and making a mess. Nothing is more unsightly than a collection of tins suspended under dripping valves and cocks. Generally these are not emptied until the water overflows and runs down cracks and crevices, thus setting up corrosion.

A very severe accident happened recently due to the failure of a badly corroded steel joist in a boiler house, and although in that case the source of the water responsible for the corrosion could not be traced, the incident serves to show the great importance of preventing water from leaks finding its way to unseen places where it may prove dangerously destructive.

Water fittings now call for consideration.[1]

The feed-check valve (and, if there are two independent feed ranges, the auxiliary feed-check valve) should be of ample size to safeguard the pumps from any undue pressure. These valves should be easily accessible, and there are two distinct ways of achieving this. The better and safer method is to insert an emergency check valve between the main check valve and the boiler. By shutting the emergency valve and stopping the supply of feed water the check valve may be rapidly opened up without any fear of personal injury. The other method is to design the feed-check valve in such a manner that it may be examined when the boiler is at work.

When two valves are situated one over the other, the upper valve being connected to the regulating spindle and the lower being a non-return valve, then, if the valve casing is designed with a joint, the lower valve may rest on a seat incorporated in the lower half of the body of the valve. By removing this lower portion the valve may be examined and, if necessary, the passages cleared from any obstructions.

All feed-check valves should be fitted with proper glands, which will not leak.

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[1] *Standard Conditions for the Design of Water Gauges*, 1920.

Stuffing-boxes are often too shallow, and only hold a couple of turns of packing. When the packing in the stuffing-box becomes hard, undue pressure is likely to be exerted on the gland in an effort to stop the leak. Under this treatment the gland bends and often cracks through the centre.

Feed-check valves are generally covered with dirt, which finds its way into the stuffing-boxes and rapidly grinds away the spindle. This fitting should be one of the heaviest and best designed of all the apparatus used on or about the boiler.

The valves themselves are frequently far too lightly constructed and, due to the constant hammering action which they cannot withstand, crack round the guide. Fig. 191 shows a solid valve in which the metal is of a good thickness between the wings.

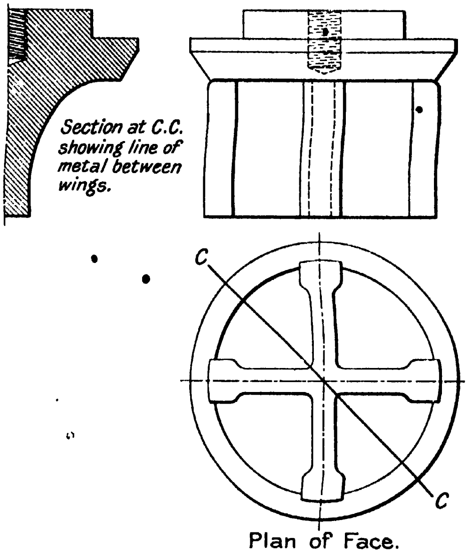

FIG. 191.—BOILER FEED CHECK VALVE.

If the valves give any trouble it pays to take them out whenever a boiler is open for cleaning, and to substitute new valves of a heavier pattern.

All feed-check valves should have spindles screwed on the outside and passing through steel bridges.

There are a variety of water-gauge glasses. In some designs the gauge glass is fitted direct on to the boiler shell, whilst in others it is attached to a hollow column; in other cases it is fixed to a solid column. When it is fitted direct to the boiler no serious trouble can arise, except that the pads riveted to the front plate to take the flanges of the gauge glass fittings may not be in line when viewed from the side. One pad may project slightly more than another, but what generally happens is that the surfaces of the two pads are not in the same plane, but one may be vertical (which is correct) whilst the other slants. When gauge glass cocks are fitted to such pads the nuts holding the glass will not be in line. To prevent leaks the nuts have to be tightened to the point at which the glass breaks. If gauge glasses on a particular boiler are constantly breaking the engineer-chemist should "line up" the pads and the trouble will probably cease.

Gauge glasses should always be fitted with glass protectors to avoid personal injury when a glass does go.

In many cases the gauge glass cannot be fitted direct to the boiler on account of the construction. With marine boilers the smoke-box is in the way. In the case of multiple drum water-tube boilers the gauge glass is usually connected to the centre steam drum. In both these cases the gauge glass is fitted to a solid or hollow column and connected by means of pipes to the steam and water spaces respectively. The pipes should be well lagged and straight, though not necessarily horizontal. There must be no bends, as these will form water pockets.

In some water-tube boilers the steam pipe is taken over the man-hole of the front drum, and in others it dips underneath. The former arrangement is not good, but the latter can only be described as very bad.

The pipes should be connected to an asbestos packed cock attached to the shell by a flange and four studs. Steam or water can then be shut off, should a joint in the water gauge pipe give trouble.

Good gauge glasses are provided with small balls in the steam and water connections, so that when the glass breaks the pressure forces the ball into its seat, and the cocks can be shut without exposing the attendant to the danger of scalding.

In many asbestos-packed water gauges the same nut is used both to compress the packing in the glands and to hold the plug in position This is a most objectionable arrangement, because, when the threads of the nut become worn, the plug is liable to be blown from the body of the gauge.

The importance of examining the erosion of the boiler shell around the gauge glass fittings has already been stressed The pipes, and the passages in the gauge glass, must be conscientiously cleaned and examined before the boiler is again put to work.

Our consideration of pressure and water gauges must not omit the problem of their illumination at night. The electric lights in the boiler room are often located where they could most easily be fixed, without regard to the efficient lighting of the gauges In some plants the electric fittings have become corroded, and smoky hand lamps are used. Where there is such a complete lack of interest in the firehole many accidents occur which might easily have been prevented The National Boiler and General Insurance Company have patented an illuminator which can easily be fixed to any gauge glass, and which has the effect of showing the water in the glass as a golden column that can easily be seen in the dark.

It is very difficult to tell whether a glass is full of water or not, especially when a boiler has been standing with banked fires for any length of time. A boiler may fill up if the check valve leaks, or in the case of pumps the speed of which is regulated by a float actuating the steam valve, an undue leakage of water will cause the pumps to continue working when the boiler is already sufficiently supplied. In these circumstances the water in the gauge glass will rapidly mount out of sight. As this is a very dangerous condition of affairs, the man in charge cannot afford to be in any doubt whether a glass is full or empty. The difficulty can be overcome by drawing a small square on a piece of paper and holding it behind the glass. If the square is distorted by refraction of the rays of the light, the glass is full of water. Both effects are shown in fig 192.

In view of the serious possible consequences suggested by the foregoing remarks, the engineer-chemist will give careful thought to the opportunities provided by "cleaning time" to make all improvements necessary to secure the highest degree of safety and efficiency.

All boilers are fitted with blow-down valves or cocks. These must be of extra strong design to enable them to withstand very severe shocks. Should they fail at any time there is likely to be a nasty scalding for someone.

The Board of Trade make it compulsory on board ship to fit a valve chest containing two valves in separate compartments, one valve being a non-return screw-down valve similar to a boiler feed-check valve, and the other a screw-lift valve attached to the spindle by means of the usual horseshoe device. The water lifts the check valve, and then passes down through the screw-lift valve. The check valve prevents anybody from being scalded, even should it inadvertently be opened while another boiler is being blown down and men are at work cleaning inside. The installation of the screw-lift valve is a precaution to ensure that in case the check valve leaks no large amount of hot water shall run to waste when the boiler is at work.

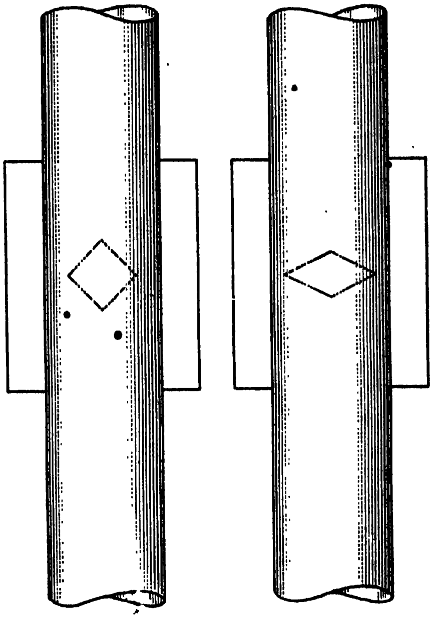

FIG. 192.—TEST TO ASCERTAIN WHETHER GAUGE GLASS IS FULL OR EMPTY.

On shore the insertion of an isolating valve, which need not be of the screw-down pattern, is strongly recommended, because there exists the very dangerous habit of leaving the blow-down valve open to allow all the water to drain away after the boiler has been emptied. If the water is run out of the boiler in a proper manner, as described in Chapter XV., and the steam and feed-check valves are in proper condition, there should be no water to drain away; but this, alas! is seldom the case. If mechanics only realized how constantly they expose themselves to the risk of scalding and of a slow and terribly painful death, and if plant-owners would insist upon such a simple precaution as inserting an isolating valve between the blow-down valve and the main pipe range, accidents of this type would be far less frequent than at present.

Where water-tube boilers are used the installation of an isolating valve is particularly important, because if the tube ends are uncapped and the blow-down valve of an adjoining boiler is opened, the person standing in front of the boiler is liable to be severely injured. The importance of fitting a copper expansion bend between the blow-down or isolating valve, if this exists, and the main range was pointed out in Chapter XI. When the engineer-chemist is making his internal inspection he should pay particular attention to the cast steel blow-down elbow pipe attached to the boiler and the copper expansion bend. Due to the abrasive action of the feed water inside and corrosion encouraged by the presence of wet ashes on the outside, these pipes often become very thin. Fig. 193 is an illustration of grooving round a bolted joint.

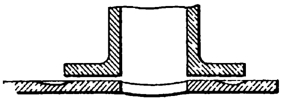
FIG. 193.—CORROSION ROUND A FLANGE JOINT.

If a blow-down cock is fitted, the cover must be provided with a guard having a slot in such a position that the box spanner, which also has a small projection, can be inserted and withdrawn only when the cock is shut.

Small cocks fitted to the shell direct should conform to the standard suggested for steam cocks. No consideration of expense should be allowed to prevent the fitting of a valve rather than a cock, especially if the fixture is constantly in use.

A final word is necessary in connection with gate, sluice, or as they are often called full bore valves These valves are often fitted with a *left*-hand screw, and in many designs the screw is incorporated in the valve itself Such valves must be condemned outright when found in steam ranges They may be used for low-pressure water pipes, inlet to centrifugal pumps, etc., but if the engineer-chemist finds any on his plant he should immediately order a fitter to attach a brass tell-tale plate to the valve and a pointer to the spindle so that it can be seen whether the valve is open or shut.

A very famous example of the sort of mistake to which valves of this type lend themselves was provided during the construction of the Severn Tunnel.

In 1879, it will be remembered, a tremendous inrush of water from what was known as the Great Spring, flooded the workings and brought operations to a standstill. Vast quantities of water had to be pumped out before further progress could be made with the undertaking. This task was rendered more difficult from the fact that a door had been left open in the long drainage heading under the river. To facilitate the work of pumping, divers were engaged to close the door and to screw down a 12-inch sluice valve which was believed to be open also. After several perilous trips Diver Lambert succeeded in closing the door, and, as he was instructed, in operating the valve. No beneficial results, however, followed, and it was not until a great deal of labour had been wasted in clearing the drainage heading that the discovery was made that the valve had, for some reason unknown, been fitted with a left-hand screw. Actually it was closed when Diver Lambert arrived on the scene, and by him it was opened! As soon as the valve was again closed, the water-level in the sump and the pumping shafts began to fall rapidly.

(*c*) *Hand-Fired Furnace.*—From his notes made while the boiler was at work, the engineer-chemist will know exactly where repairs are required at the boiler front and to the furnace fittings. While the gear is being taken adrift he can give detailed instructions concerning the work to be done.

Front fittings include the door, ashpit plates, damper regulating gear, and possibly steam jets. Then come the front dead plate, firebars, bearers, back bearer, and division plate. The firebridge will be considered under Boiler Brickwork in Chapter XVII.

The furnace door is an important item, as explained in Chapter IV., because any air that leaks past it reduces the efficiency of the boiler. Hinges of furnace doors often become badly worn, and the door, instead of swinging about a vertical axis, falls open anyhow. The remedy obviously is to fit new hinges and pintle.

The door is supplied with a secondary air-supply shutter which will usually be found either slack, so that it moves at random, or badly burnt. As firemen very rarely regulate this shutter, it is best to fit a new plate and hold it in position by four screws of ⅜-inch diameter. The door itself is protected by a guard plate or firebrick tile. When firemen pile all the fuel high on the front dead plate the firedoor guard becomes burnt, and may need renewing. Although firedoors are provided with handles, these become too hot to touch, and as many firemen do not wear a leather shield, the shovel is frequently used as the handiest implement with which to pull the doors open and to bang them shut. To make an end of this undesirable practice the engineer-chemist should have the necessary number of ring openers made. An opener like that shown in fig. 194 can be made in the workshop at a very small cost.

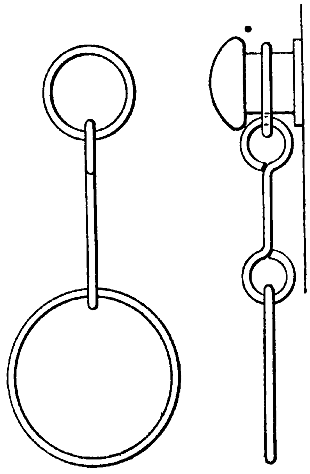

FIG. 194.—RING HANDLE FOR FIREDOOR.

The ashpit dampers should be tried in place to make sure they are not bent or burnt. If damaged, they are of little value, and in that case it will not be safer to use them in preference to the side-flue dampers, as recommended in Chapter IV. The damper plates are frequently used for all sorts of purposes, such as making a ramp for wheelbarrows, and as a result of this ill-treatment they lose their shape. They also corrode rapidly, being often in contact with wet ashes whilst cleaning fires is in progress.

The damper gear needs no special attention beyond seeing that the pulleys are clean and well oiled, and that the damper plate, if of the drop pattern, works up and down without sticking.

In the grate itself are a number of items requiring careful inspection. All the firebars should be pulled out and examined to make sure that they are not broken, buckled, burnt, or covered with hard clinker. Fig. 195 shows the air-space between ordinary firebars. The front dead plate, together with the back and intermediate bearers, should be removed, and the studs in the furnace examined for signs of burning or corrosion. The failure of a single stud may not be a very serious matter, but if the grate falls there will be considerable delay before a temporary support can be rigged up and the hole plugged. If a factory has no reserve boiler power the loss of a steaming unit may mean that a large number of hands in the factory are compelled to cease work, only because one rotten stud has given way.

The air-space between the firebars is, of course, of tremendous importance, and if the bars are too wide or covered with scale they should be planed down or thoroughly chipped.

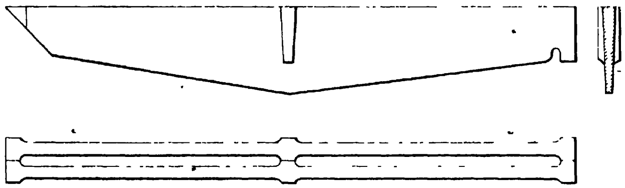

FIG 195 – AIR SPACE BETWEEN FIREBARS

Furnaces often leak, and the fluid that runs from the fissures sets in a hard white scale. After the grate has been pulled out, the whole of the interior must be made spotlessly clean before any caulking or patching is commenced.

Proper inspection of the furnace includes an examination of all the firing tools belonging to it. Rakes that are burnt should have a new end welded on, and bent slices should be straightened. Firing tools are not infrequently lost, mislaid, or borrowed by outsiders, who conveniently forget to return them. An inspection of the tools every time a boiler is cleaned will ensure that a set of firing tools is provided for each boiler.

(*d*) *Mechanical Stokers*.—Inspection of mechanical stokers falls naturally into three sections:

Examination of the working parts.
Examination of the grate.
Examination of the driving mechanism.

The amount and character of the work required varies with the type of stoker.

In the sprinkler stoker as fitted to Lancashire boilers, the two most important items are the gear operating the shovel and that moving the grate. The springs of the former require close attention, because they are apt to become "tired" and lose some of their force. The tappet which compresses the spring becomes worn, but as it is generally provided with a separate piece of hardened steel similar to that fixed to the tripper arm, the renewal of the worn plate presents no difficulty.

The bearings become very slack, due to coal dust finding its way into every part, however well it may be protected. The simplest proceeding, when the boiler is under inspection, is to disconnect the hopper from the boiler front and to send it to the fitting shop to be thoroughly cleaned and overhauled. Not only will the work be done better, but it will also be finished more quickly than is the case when three or four men get in each other's way, all working at the front of the boiler.

Grease boxes should be cleaned, and the pipes tested for free passage with a stout wire.

All the bars should be removed from the grate, and any which are burnt should be replaced by new ones. Owing to the very fine air-spaces possible with these grates, because steam jets are invariably used to force the air through the bars, special care is necessary when examining the round-topped grids. It is advisable to withdraw all the troughs in the Bennis type stoker for examination and cleaning.

The transverse driving shaft which runs along the front of the furnace and moves the bars or troughs in and out of the furnace is fitted with cams, generally made of highly chilled cast-iron wedge-wearing pieces. This shaft is, as a rule, lubricated with a copious supply of black axle grease, but sometimes it is neglected. In the latter case the cams wear, and the bars do not travel their full stroke into the furnace.

Some mechanical stokers are supplied with " best nuts," having a high calorific value and low ash content. There is not enough ash to protect the firebars from the fierce heat given out by the burning fuel. Thus the firebars or grids become burnt.

The driving shaft, bearings, brackets, driving belt, spur and bevel gearing, should be cleaned and examined, but this is the work of an ordinary fitter.

Water-tube boilers are generally equipped with chain grate stokers. For inspection purposes the whole stoker is withdrawn from the boiler, and a squad of men can work on this part of the unit without interfering with men engaged taking off the tube caps, etc.

The engineer-chemist will see that every part of the work is done in accordance with a proper routine. To " work anyhow," instead of keeping to a routine, is to waste a large proportion of the total time spent on the job. Nothing causes more delay than the mismanagement which compels one man to wait for another, whether because suitable tools are not available, or because a pipe has been kept under pressure and cannot be removed promptly, or because men assigned to a particular piece of work arrive on the scene only to find someone else at work on another job connected with the same piece of apparatus.

Some water-tube boilers have very long chain grate stokers, and the pit, as often as not, slopes down towards the boiler. If there is plenty of room between the front of the boiler and the boiler-house wall, the removal of the stoker, with the aid of a couple of good chain pulley blocks, presents no difficulty. Far too often, however, the available space is very restricted, and the stoker has to be slewed. If the slope of the stoker pit is steep and near the front, the operation of slewing the stoker is very awkward, and consumes much time. A little practical consideration in this respect on the part of designers would be very helpful. In many cases their only care seems to be to make such allowance as would be necessary if the stoker were a piece of paper on a drawing. It is one thing to juggle with a piece of paper and a plan, but quite another to lift or slew a heavy stoker to clear some projecting pipe or fitting on the boiler-house wall, not allowed for in the design. Such additions and projections are very common, and the failure of the designer to allow for the smallest deviation from his plan is the occasion of not a little waste of energy and loss of temper when later on a stoker has to be removed. Sometimes the damage is also structural, and the writer knows of cases where parts of the bunker wall had to be broken away in order to get the last 2 or 3 inches of necessary clearance.

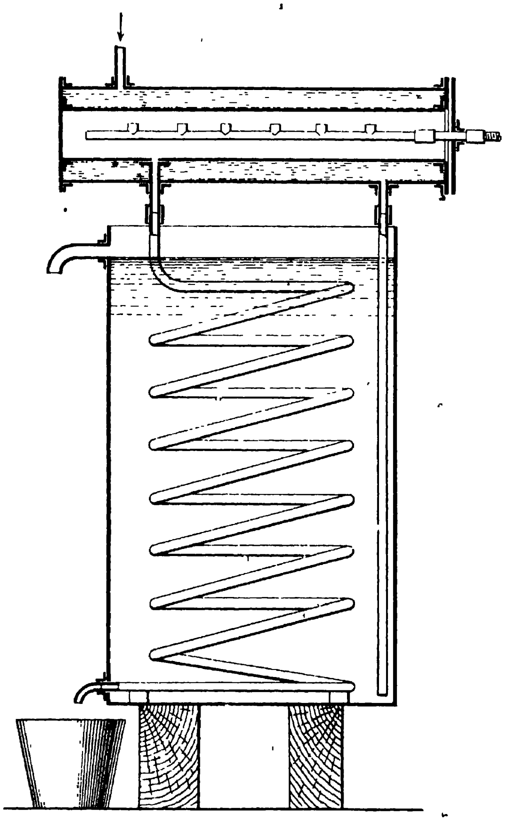

FIG. 196.—APPARATUS FOR TESTING STEAM CONSUMPTION OF STEAM JETS.

Chain grate stokers require similar treatment to that already prescribed for the sprinkling stoker. The driving shaft, variable speed gearing, front and back stoker rollers, all bearings, etc., should be cleaned and examined for wear, with special reference to the oil gutters in the bearings.

The links in the grate should all be examined for signs of clogging and burning. It is, of course, of vital importance that the different sections of the grate should each receive their proper supply of air, and if a section of the chain grate is clogged with fused clinker, the efficiency of combustion will fall every time the clogged part comes into service.

Compartment chain grate stokers, fitted with a steel air casing under the chain grate and divided into sections so that the air can be regulated to a nicety, require special attention. The chain grate should be dismantled, if necessary, and the plates of the air casing, as well as the shutters, thoroughly cleaned with wire brushes and painted with two coats of brown oxide of iron and boiled oil.

The dumping bars at the back of the grate may require to be renewed, and if the stoker is of the enclosed type a sharp lookout must be kept for air leaks.

Before the stoker is replaced, all the steel and iron parts, such as the frame, hopper, and bearers, should receive thorough cleaning. They should also be painted with a good mineral black, mixed with linseed oil and a little kerosene oil. By the term " thorough cleaning " is meant the brushing away of all loose dirt, scraping with steel scrapers, and a final strenuous application of wire brushes to remove all traces of dirt.

Mechanical stokers are driven either by a belt from an overhead shaft or by an enclosed motor. In some cases, as, for instance, in the underfeed chain grate stoker, the fans are incorporated in the stoker and are electrically driven. In large power stations the forced and induced draught fans are always motor-driven, and accordingly the engineer-chemist must have a good working knowledge of electrical machinery, with special reference to continuous current motors. This machinery seldom gives much trouble; but if a motor, part of a motor, or starting panel is disconnected for cleaning, it sometimes happens that the wires are wrongly connected when the parts are reassembled. The rule for a shunt motor is that the starter resistance must be placed in series with the armature, while the shunt winding is connected parallel to the armature and the starter. In that case the shunt stands under full pressure when switching in, while the armature current is weakened by the resistance connected in series with it.

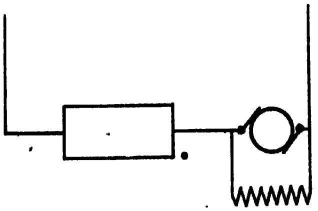

FIG. 197.—FAULTY CONNECTION OF STARTER FOR SHUNT MOTOR.

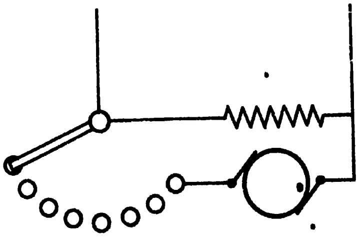

FIG. 198.—OLD METHOD OF CONNECTING STARTER TO SHUNT MOTOR.

Under no conditions must the connections be made as in fig. 197, which shows the shunt in parallel with the armature alone. A motor thus installed will not start.

Until recently the arrangement shown in fig. 198 was adopted in order to prevent sparking when starting the motor; the shunt winding connected directly to the leads remains in circuit at the end of the run until opened by a special switch when the motor is stopped.

Any sparking may be prevented by connecting up, as shown in fig. 199.

The terminals of the starter are marked "line," "field," and "armature." A thin lead is used from the shunt terminal to the free end of the shunt winding and a thick lead from the armature to that pole of the machine which is not directly connected with the shunt winding. These connections are shown in fig. 200.

A mistake very often made is shown in fig. 201, in which case the marks on the resistance have been used correctly, but the wrong pole is connected—that is, the return lead is taken from the free pole.

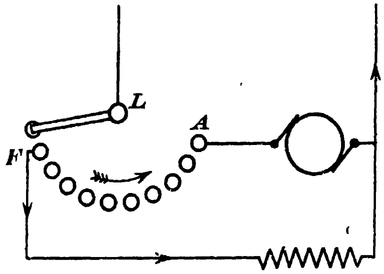

FIG. 199.—NEW METHOD OF CONNECTING STARTER TO SHUNT MOTOR

Electric lighting, as well as power, must be watched by the engineer-chemist. Wires often pass near metal, and when the insulation becomes worn from vibration or other cause, an earth is made. If two lamps are connected, as shown in fig. 202, they will both glow with equal intensity.

Immediately an earth occurs, one of the lamps will glow and the other will burn brightly, showing that there is an earth. If the positive lamp burns brighter, then the earth is on the negative lead, and *vice versa*.

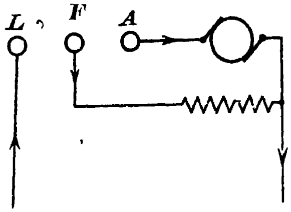

FIG. 200.—CORRECT WAY OF CONNECTING LINE, SHUNT, AND ARMATURE

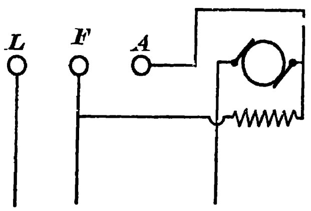

FIG. 201.—INCORRECT WAY OF CONNECTING LINE, SHUNT, AND ARMATURE

(*e*) *Steam Jets.*—It was mentioned in Chapter IV that the steam used by the steam jets should be periodically checked to ensure that the cost of the fuel burnt to supply them with steam is not out of all proportion to their utility.[1] The simplest manner of testing their consumption of steam is to use the apparatus shown in fig. 196. This can easily be made in the workshop. It consists of a large tank in which is placed a long coil of pipe. The tank is fitted with two bearers in which rests a horizontal cylinder. This cylinder is made with a water jacket, and is so arranged that one end cover can be removed. The whole apparatus is placed in the "firehole," near the boiler to be tested. The front pipe, with steam jets attached, is disconnected at the stop-valve and coupled to a nipple passing through the end cover of the cylinder. The cover is replaced and the outside end of the nipple connected to the stop-valve which ordinarily supplies the jets with steam. Circulating water enters the horizontal cylinder at the top, flows round the jacket, and is conducted by a long pipe to the bottom of the tank. The water, already warm, tends to rise, and leaves the tank through an overflow pipe fitted at the top. The steam leaves the jets under ordinary atmospheric conditions, because it is condensed by the water which is not sufficient to create a vacuum nor insufficient to allow a pressure to accumulate. The steam and condensed steam next pass through the cooling coil, which terminates outside the bottom of the tank, so that the condensate can be collected in a bucket.

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[1] "Steady Flow of Steam Through a Nozzle or Throttle," H. L. Callendar, *Trans. Inst. Mech. Eng.*, 1915, p. 53.

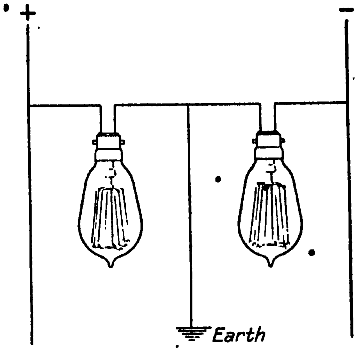

Fig. 202.—Earth Lamp Test.

It is usual to run several tests, each lasting 15 minutes, and to weigh the steam condensed in that time.

The weight of steam multiplied by 4, if the test is for 15 minutes, and by 2, if only one furnace is tested, divided by the hourly evaporation of the boiler in pounds, and multiplied by 100, will give the value of the steam consumed by the jets as a percentage of the total steam evaporated. This should not exceed 5 per cent. at the outside. The steam pressure should be that at which the boilers habitually work.

Some patent furnaces are fitted with steam jets at the back of the grate. Such an arrangement can only be tested when the boiler is being repaired. The jet bar must be taken out and supplied with steam from a neighbouring boiler working at the same steam pressure as that at which the boiler under repair is usually operated. A frequent examination of the nozzles is necessary to make sure that the small pinhole has not become enlarged to $\frac{1}{8}$-inch diameter or more.

Firemen will invariably keep the regulating valve fully open, and it is advisable to install a master valve as well as a reducing valve which can be locked, so that high-pressure steam cannot be obtained at random. A fan is far superior to steam jets as a means of creating draught, and where jets are used to assist in keeping the firebars cool, as in most mechanical stokers, the pressure should not exceed 60 pounds per square inch. A plant comprising eight Lancashire boilers can with ease run up a fuel bill of £1,000 per annum simply for the supply of steam to the jets.

CHAPTER XVII

BOILER BRICKWORK

THE boiler brickwork may be divided into five sections.

(*a*) Foundations.
(*b*) Seating.
(*c*) Flue covers.
(*d*) Walls.
(*e*) Internal brickwork.

(*a*) ***Foundations.*** The engineer-chemist cannot alter the foundations, but he can watch their behaviour and take such measures as may be necessary to remedy any trouble due to the development of cracks, settling, etc. The foundations of boiler plants are frequently insecure, and although modern boilers are generally set on a sound concrete foundation, old plants often show signs of subsidence, which means that considerable external stresses are set up in the boiler. The first symptoms of subsidence in the case of Lancashire boilers are cracks right through the brickwork.

If a boiler plant is near a hill or on low-lying ground, which may be very moist in winter and correspondingly dry in summer, there is every likelihood of subsidence. In such conditions the engineer-chemist will need to keep a specially keen watch for displacements of the foundations and superstructure. Many boiler plants work with water in the flues during the winter months. This is very frequently the case with open-air plants. Moisture and damp brickwork are the most usual causes of rapid external corrosion, which weakens the boiler plates to such an extent that an explosion eventually takes place. Fig. 203 shows the result of a Lancashire boiler explosion following upon a weakening of the plates due to unsuspected corrosion.

Boiler plants built on clay soil are immune from settling, provided that the foundations have been properly laid, and that the natural formation of the clay is not subsequently disturbed.

During the last coal strike several water-tube boiler owners adapted their boilers to consume oil fuel. No furnace fittings being required in burning the new fuel, the whole of the lower portions of the furnaces, which had previously served as ashpits, were subjected to the fierce heat generated by the liquid fuel. A layer of firebricks was placed in the stoker pit, but this protection was utterly inadequate. In several cases clay subsoil became baked, the extraction of moisture causing sufficient shrinkage to produce severe cracking of the walls.

If the works are situated in a rocky valley—paper mills in the northern counties often lie in charming surroundings of this character—the oozing of water from a large number of crevices may result in serious trouble, and a special drainage system may have to be devised. It is very inadvisable to allow natural rock to form one side of a flue or economizer chamber, because cracks may form and allow water to trickle through. For obvious structural reasons it is impossible to keep the potential sources of trouble under constant observation.

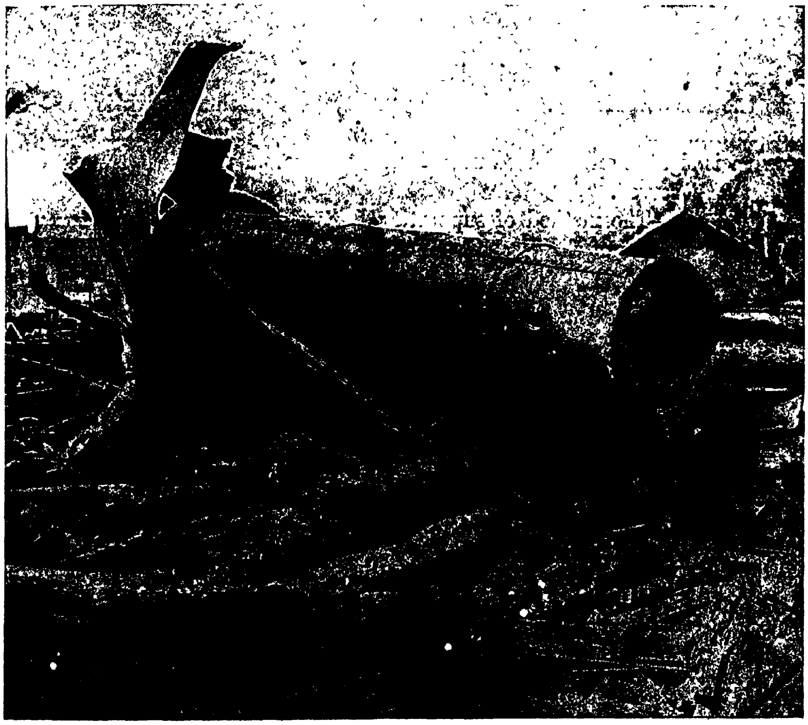

FIG. 203.—RESULTS OF EXPLOSION OF A LANCASHIRE BOILER.

Collieries, chemical works, and other factories which pump large quantities of brackish or polluted water, have experienced trouble because the water has percolated through the ground, affecting the subsoil for a considerable area. Many wells and ponds have been rendered unfit for use in this way; and the engineer-chemist will refuse all responsibility for damage caused to the boilers by impure feed water, when this is due to the action of his own firm in polluting the sources of supply.

Vibration is another cause of foundation trouble. Heavy steam hammers, beating machines, and similar apparatus, should not be erected near a boiler house;

or, if the proximity is unavoidable, the foundations of such machines must be underpinned.

If flues or a chimney show signs of subsiding, the engineer-chemist should have a slab of reinforced concrete sunk in the ground to the depth of at least a foot. The slab should be at least 6 feet square. This slab will be used to support a small square column of concrete about 9 inches square, the height of the column and the position of the slab varying according to the part which it is desired to keep under observation. The foundations for the slab and observation column may have to be taken to a considerable depth to make absolutely sure that the slab itself cannot subside. An ordinary surveyor's level is placed on the pillar and sighted on a mark made on some object which is not subsiding. The telescope is next sighted on to the flue or chimney that is subsiding, and an indelible mark is made. In order to find out at any time whether a further subsidence has taken place, the telescope is sighted on the fixed mark and swung round until it is trained on the mark to be observed.

(*b*) *Seating.*—The method of supporting Lancashire boilers is very important. The bearing surface of the blocks is usually ample, but the blocks themselves are of such a shape and so placed that the joints are not gas-tight, and the products of combustion pass from under the boiler straight into the side flues. The blocks are also frequently of an unhandy size, which causes unnecessarily hard labour when the engineer-chemist requires their removal for purposes of inspection. It is necessary that a clear distinction be made between the bearing surface of the blocks and that of the foundation walls by which the weight of the boiler is transmitted to the ground. The area of the walls on which the blocks are placed is frequently insufficient.

Modern practice is to use blocks with a groove in which runs a continuous asbestos rope. This rope is flattened by the weight of the boiler, and makes an air-tight joint. The blocks are also constructed in such a manner that they can easily be withdrawn to permit of a thorough examination of the seams.

External corrosion is, in the majority of cases, due to moisture leaking past the brickwork or to damp brickwork in contact with the plates. This wasting may show itself in any one of the forms mentioned in Chapter XV when dealing with corrosion. Fig. 204 shows the effect of dampness on the base of a vertical boiler. This is an example of surface wasting.

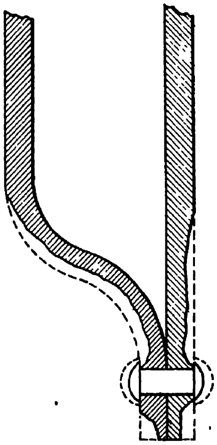

FIG 204.—CORROSION AT BASE OF A VERTICAL BOILER.

Whenever a boiler is cleaned, all the shell seams should be examined, and in order to make sure that there is no corrosion anywhere, the seating and flue cover blocks in the way of all riveted joints should be removed. The actual inspection occupies but a short time, but the preparation is tedious and expensive, except where modern methods of boiler setting have been adopted. A heavy pattern seating block, with the minimum of bearing surface consistent with maximum strength, is shown in fig. 205 at "A."

Seating blocks should be of such a shape that they cover as little of the heating surface as possible.

Faulty setting is responsible for inefficient operation in a great many boiler plants. The brickwork is pushed outward when the boiler expands, but cannot follow the motion of the boiler when the latter contracts. Consequently the mortar, cement, or fireclay by which the bricks are held together becomes loose, and the walls begin to leak badly. This means that the air, instead of passing through the bed of fuel on the grate, is drawn in through the various cracks in the brickwork and consequently diminishes the draught. In natural draught plants this is fatal to efficiency.

(c) *Flue Covers.*—The foregoing remarks also apply to the method of covering the side flues, but in addition the flue covers should be designed in such a manner that cleaning the outside of the boiler may be done at any time without pulling down any complicated masonry. Boiler plant owners have been exceedingly slow in appreciating the advantages, from the point of view of maintenance and economical operation, of modern improvements in the art of boiler setting, and still allow boilers to be installed in the antiquated fashion. Frequently the whole of the front wall has to be demolished to allow men to get into the side flue.

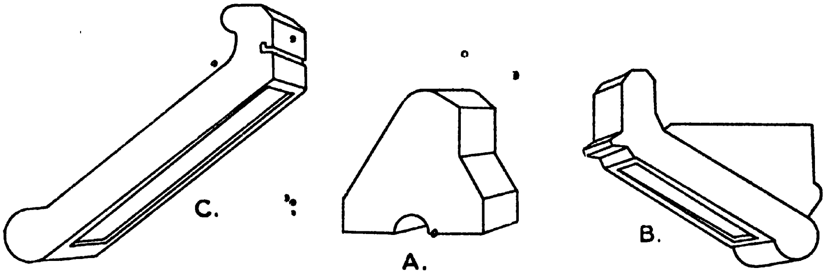

Fig. 205.—Boiler Setting Blocks.

Small round inspection doors are of little use, except for the nozzle of a vacuum pipe where special flue-cleaning plant of this character is installed.

Surprisingly often do designers of boiler settings overlook the fact that men working in the flues cannot breathe flue gases. It is just as important that they should be supplied with air as that there should be room for them to move.

Flues should be cleaned more frequently than boilers, and the week-end, when the boilers are banked down, is very convenient for this purpose. If, however, the draught is very bad, the gases remaining in the flues after the side dampers have been shut will not be swept away by a current of fresh air, and also the boiler will take very long to cool down. This, of course, means that there is not sufficient time to clean the flues before the boiler is required again. As already stated, boilers must not be cooled too rapidly, but this does not imply that they should be incapable of efficient ventilation when cold. If it is necessary to pull down the front wall to enable men to enter the flues, flue cleaning is probably impossible during a week-end. The efficiency of the plant, however, will constantly decrease until the necessary cleaning is performed.

The whole of the side flue and down-take covers must be designed in such a manner that they can easily be lifted, and the soot cleared from the flues. The outside of the shell will also require to be brushed over with wire brushes. The Milner Hurd patent inspection system of setting boilers has been introduced to meet such requirements.

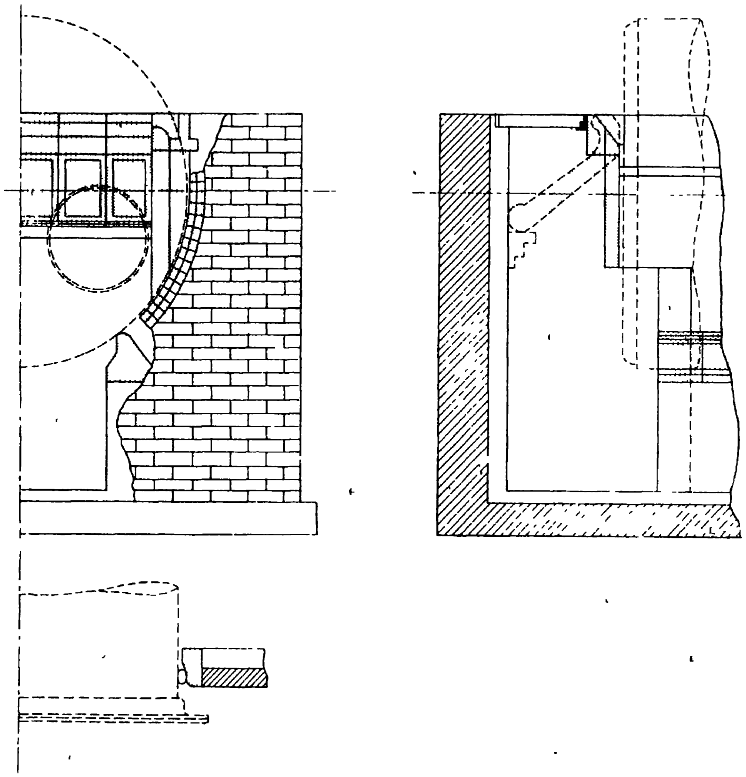

FIG 206.—MILNER HURD PATENT RADIAL STUFFING-BOX FITTING FOR FRONT WALL AND SLIDER BLOCK FOR DOWNTAKE COVER

The ordinary method of building the front wall is to bring the brickwork close up to the boiler. Obviously, when expansion occurs, displacement of brickwork is bound to follow, resulting in air leakage and consequent loss of fuel. To overcome this difficulty patent radial stuffing-box bricks are used (fig. 206).

These are built half an inch clear of the boiler shell, and an asbestos rope is inserted, which stops up the space and allows the boiler to expand without touching the brickwork, except round the blow-off recess, which assists in supporting the weight of the boiler.

The covering of the side flues is another point which is considered. The usual method is to use an arched brick with two or more courses of brickwork on top, as shown in fig. 207.

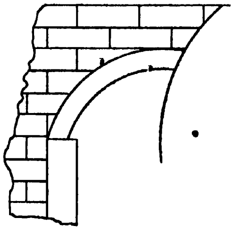

FIG. 207.—USUAL METHOD OF COVERING SIDE FLUES.

This construction is perfectly rigid, and does not allow in any way for expansion, which is bound to take place and to result in cracked brickwork and air leakage. It will readily be seen that all air leakage must interfere with the draught and cause a further loss of fuel. By using special side-flue covers, as shown at "B" in fig. 205, this trouble is eliminated. Not only do the covers prevent cracking of the brickwork and air leakage, but they can be taken up in a very short time with the minimum of labour and replaced in an equally easy manner.

The importance of having the brickwork at the back end of the boiler so arranged as to provide for expansion cannot be over-estimated, as it is at this end that there is usually a very bad wastage of fuel, due partly to cracked brickwork and consequent air leakage, but even more to hot gases in the down-take by-passing between the boiler end plate and the down-take side wall into the side flue, straight to the chimney, instead of taking their proper course through the flues and distributing their heat over the boiler shell to produce steam. The amount of fuel wasted in this manner is very considerable. Assume that between the boiler end plate and the down-take walls there is a gap with a mean width of half an inch, and that the walls are 5 feet high, giving a total area of 60 square inches, there would be a loss of approximately 10 to 15 pounds of fuel per hour. A useful formula for finding this loss is as follows:

$$\frac{A \times V \times W \times 3{,}600 \times T \times 0{\cdot}25}{12{,}000}$$

where A = area of gap in square feet.

V = velocity of gases in feet per second.

W = weight of gases per cubic foot.

3,600 = seconds per hour.

T = difference of temperature between the down-take and side flue.

0·25 = specific heat of gases.

12,000 = average calorific value of fuel.

The loss varies, of course, according to the furnace efficiency.

The Milner Hurd anti-short-circuiting device deals with the above-mentioned faults in the following manner:

The down-take side walls, instead of being square and built close up to the boiler end plate, as at "A" in fig. 208, are built 1 to 1¼ inches clear, and have special recessed brick to provide suitable space to accommodate a specially woven long fibre asbestos rope, shown at "B" in fig. 208.

It is important to emphasize the fact that the asbestos rope is a speciality in itself, as it is constructed in such a manner as to withstand the scouring action of the hot gases, and must have a certain amount of resiliency to form an effective cushion under all working conditions of the boiler without disintegrating, thus forming a seal and preventing the by-passing of the gases. The rope is held in a cast-iron slider block, the face of which rests on the boiler end plate. An anchor block, resting on the top of the down-take side wall, and having an incline of 45°,

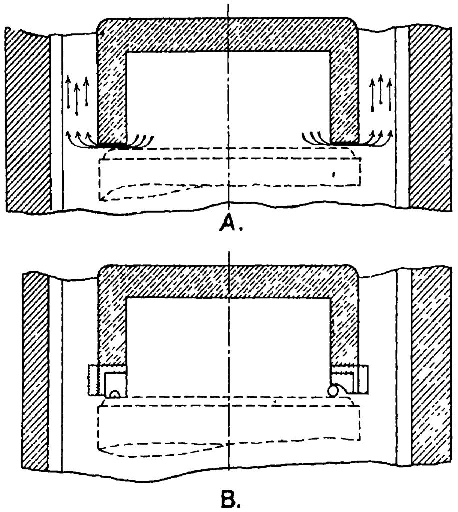

Fig 208.—Old and New Methods of Building Brickwork at Back of Boiler

accommodates the cast-iron slider block, so that, when the boiler expands longitudinally, the slider will keep the rope tight up against the boiler end plate and will fall into its old position when contraction takes place. The down-take covers, shown at "C" in fig. 205, are also designed to provide for the backward movements of the boiler. They are set at an angle of 37½°. The end rests on a ledge at the back of the down-take, and has a round smooth surface set in a bed of best quality fireclay, so that the whole can rise and fall with the breathing of the boiler. The arrangement is shown in fig. 209.

One of the great advantages to be gained by the adoption of these covers is that they can be lifted up in a very few minutes for inspection or cleaning purposes, and can be replaced just as easily.

All blocks are made of special fire-resisting materials and are steel reinforced, being much more durable than ordinary firebrick.

The general arrangement of a boiler set in the manner described is shown in fig. 210, and fig. 211 shows a Lancashire boiler with side-flue covers raised.

(*d*) *Walls.*—Boiler walls are often of insufficient strength. Firebrick lining should not be counted when calculating thickness, except in cases where the wall only acts as a partition, and therefore has not weight to carry.

If the engineer-chemist at any time has occasion to rebuild any walls, these should be not less than 18 inches thick, and if they are to be subjected to any heat, they should have a $4\frac{1}{2}$-inch firebrick lining in addition. The firebricks should be bonded with the ordinary bricks every second or every fourth course, according to the nature of the wall. Walls which have to withstand a special thrust, as is the case with side walls of water-tube boilers supporting the firebrick arches, must be stiffened or other special provision made. This special provision usually takes the form of steel framework, and special vertical and horizontal buckstays are fitted to take the thrust of the arches. The walls are built clear of all steelwork, and only enclose the boiler.

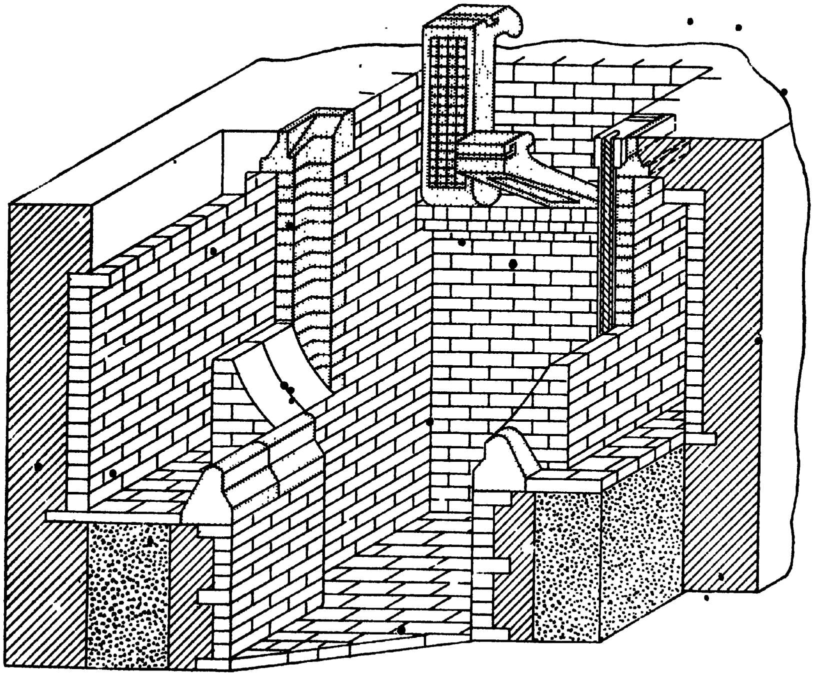

FIG. 209.—ISOMETRIC DRAWING SHOWING ARRANGEMENT AT BACK END OF BOILER.

In some cases the boilers are surrounded by steel plates protected from the heat

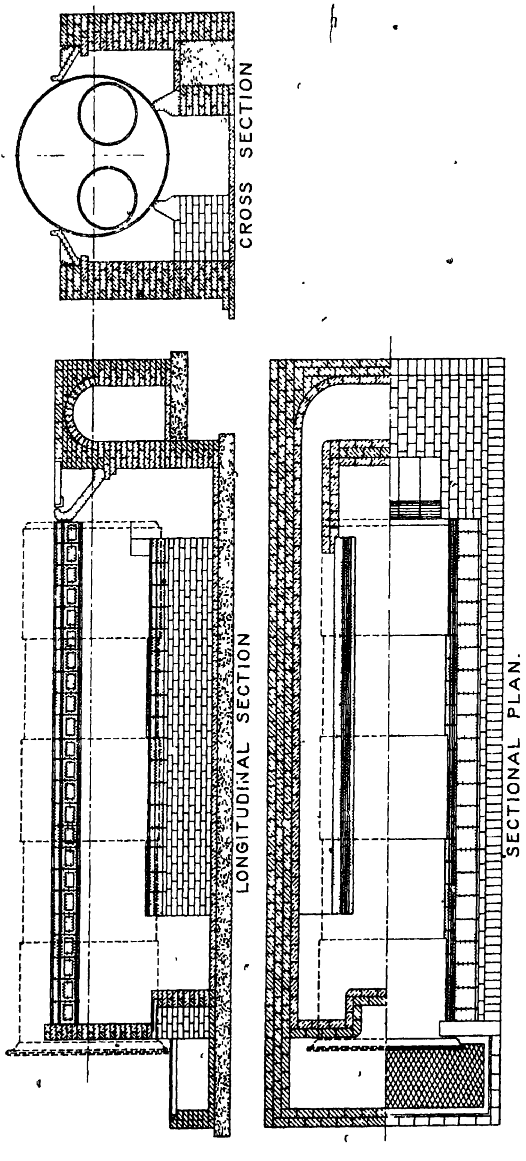

Fig. 210.—General Arrangement of the Milner Hurd System of Boiler Setting

by a firebrick lining. If the steel casing is air-tight, this arrangement is preferable to enclosing the boiler with brickwork, because steel plates will not develop air leaks. Also, the steel casing can be made durable, and the space between outer and inner plates filled with asbestos or other insulating material.

The extensive brick surface of the walls surrounding the ordinary water-tube boiler radiates very much heat, and this is one of the disadvantages of boilers of this type, when set without a steel casing. If the walls develop cracks, and air leaks into the combustion chamber, the efficiency of the unit will be diminished, especially if the boilers are worked with natural draught, as in that case the draught above the grate is considerably reduced. Cracks have a less injurious effect when forced draught is used.

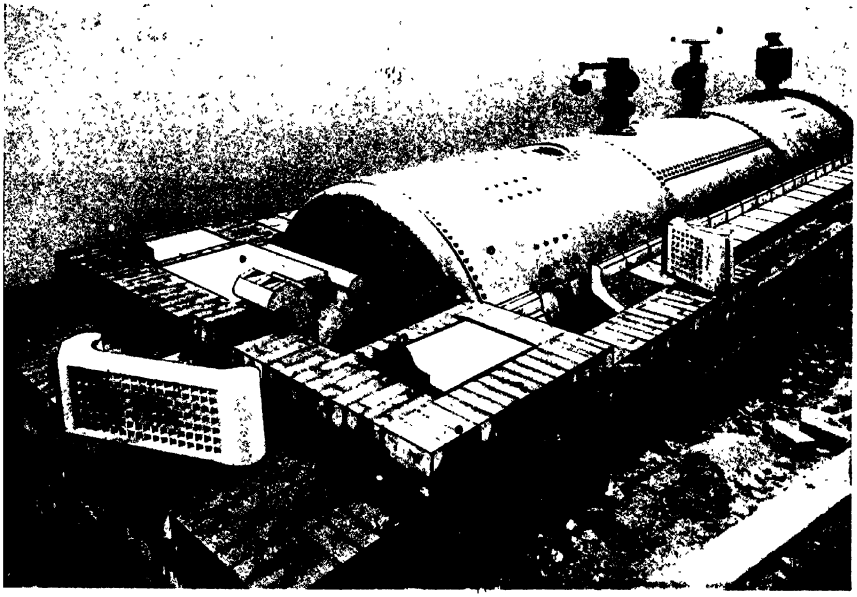

FIG. 211.—LANCASHIRE BOILER WITH SIDE FLUE COVERS RAISED (MILNER HURD SYSTEM).

The engineer-chemist will always keep a sharp lookout for air leaks of any description anywhere, and when he finds them he will immediately instruct a bricklayer to do the necessary pointing. Walls that are very unsatisfactory in this respect should be pulled down and rebuilt as soon as an opportunity presents itself for making the change.

In the building of walls considerable care is required to make sure that the mortar, cement, or fireclay will bind with the bricks. The bricklayer should never work on a frosty day, nor is it worth while to have him repair a section of a wall that is still warm or that will almost immediately afterwards be subjected to heat.

In the former case the binding material is apt to freeze before it can adhere to the surface of the brick, and in the latter the moisture is almost certain to evaporate before the bond is made. More often than not, large pieces of binding material can be removed very easily with a penknife from brickwork thus carelessly undertaken. If bricks are being laid where the air is warm, they should be first dipped in water.

It was mentioned in Chapter I. that the setting of boilers and the building of the necessary brickwork call for special knowledge. All such work should be performed, under the personal supervision of the engineer-chemist, by bricklayers having special experience in boiler setting.

Reference has also been made to special seating blocks provided with grooves to take a continuous asbestos rope. Similar blocks can be used to render the front wall of a Lancashire boiler setting air-tight. This is an admirable arrangement as far as it goes, but the wall often cracks in other places To make an air-tight job throughout, special interlocking bricks may be provided. The front course receives an asbestos rope, so that even if the binding material gives way it is impossible for any air to leak into the flues.

Glazed bricks make a boiler house look smart, and can easily be cleaned Their efficiency, however, is no greater than that of ordinary brick.

In an old Lancashire boiler plant where the draught is inadequate and the brickwork in poor condition, the engineer-chemist should be given permission to rebuild the front wall in sections, one boiler at a time When putting this job in hand he will clean the flues and repair the top brickwork of the side flues and main flue. This may have such a beneficial effect upon the plant as a whole, that it will be possible, without reducing steam output, to shut down one boiler at a time, and thus to repair the boiler seatings, superheater chamber, and other brickwork not already rebuilt.

(e) *Internal Brickwork.*- Internal brickwork comprises the following four constructional items:

(1) Lining of water-tube boilers.
(2) Arrangement of baffles.
(3) Furnace arches.
(4) Firebridges.

(1) *Lining of Water-Tube Boilers.*– The remarks made in the previous section about bonding and thickness of walls apply also to the lining of water-tube boilers, but greater care is necessary in setting the bricks and, as a general rule, the walls are much thicker than the minimum already stated. The firebrick lining is generally bonded every other course in the front wall, and every third course in the side walls, with the ordinary bricks of the outside walls.

The engineer-chemist should make a careful examination of the condition of the firebrick lining and the extent to which the bricks have deteriorated under the intense heat.

The lining of the front wall and of the front portion of the side walls and the whole of the coking arches should be of special firebrick, such as Glenboig or similar bricks. The side wall lining, with the exception just noted, should be of a good quality firebrick tested in the laboratory before use by baking in the muffle furnace and then immersing in cold water.

A misguided passion for cheapness has caused many firms to substitute ordinary brick for firebrick in the back walls and parts of the side walls of boilers. This construction is frequently possible with multiple drum boilers, but in no case is it recommended. Its feasibility is determined by the temperatures at which gases come in contact with the brickwork, and in the case of boilers in which the gases sweep direct from the furnace to the back wall before commencing their upward path, any attempt to dispense with firebrick will be attended with disaster.

Attention has already been drawn to the very serious waste of heat which occurs through radiation when the walls of water-tube boilers are of ordinary brick construction. One method of reducing this waste is to encase the boiler in steel, either leaving an air-space or packing insulating material between the steel casing and the firebrick lining. Alternatively special bricks may be used for the lining. The nonpareil brick made by Messrs. Newalls might be quoted as an example of special brick suitable for this purpose. These bricks are made from a mixture of diatomaceous earth with small percentages of special clay and cork granules. The diatomaceous earth is almost pure silica, consisting of multitudes of tiny shells each containing air. The bricks when finished owe their efficiency largely to the presence of this " still " air, but some of the credit is due to the fact that after being moulded they are subjected to a special baking process. The cellular construction left by the disappearance of the cork granules during baking largely increases the amount of " still " air in the brick. The bricks withstand a temperature of 1600° F. without shrinking, are capable of carrying a load of 130 pounds per square inch, and will save for use 90 per cent. of the heat units which would leak through ordinary red brick.

All walls must be built straight and plumb, and thoroughly grouted at each course. Well-mixed mortar, composed of one part of Portland cement to two parts of clean sharp sand, is necessary for red brickwork walls extending from the foundations to the floor level. On all red brickwork from the floor line up, well-mixed mortar, composed of one part freshly burnt lime to three parts clean sharp sand, should be used. The mortar must not be applied while hot from the slaking of freshly burnt lime.

The bricks should be laid in courses of three stretchers to one header—*i.e.*, every fourth course should be a header course.

In the multiple-drum type of water-tube boiler the mud drums hang from the steam drums. In other words, they are held in position by the tubes expanded into them. It is therefore of vital importance that the mud drums shall be free to expand, and not be held rigidly by the brickwork. The method generally adopted to meet the requirements of such boilers is to build a brick arch round the mud drums, with a clearance of 1 inch all round, which is filled in with asbestos rope.

Bricks on top of steel supporting sheets should be laid in lime mortar with the joints open at the upper edge, and after all the bricks are in place these joints should be slushed with cement, forming a layer on top of the bricks at least $\frac{1}{4}$ inch thick.

(2) *Arrangement of Baffles.*—The engineer-chemist should examine the baffling arrangements personally, because upon them the efficient working of a boiler depends to a marked degree. The arrangements vary with different types of water-tube boilers, but in the multiple drum type they consist of firebrick or cellinsulate slabs resting on the water tubes and supported by a cast-iron I or H beam let into the side walls of the boiler. These slabs should meet on the centre line of each tube, as shown in fig. 212.

Similar firebrick tiles are often placed on the wall in front of the front mud drum to provide a gas-tight seal, which will at the same time allow for a movement of the drum when the tubes expand.

The baffling arrangement deflecting the gases past and through the superheater must be in perfect order, so that the gases may neither short-circuit through the superheater and burn the tubes nor miss the tubes and produce a low superheat.

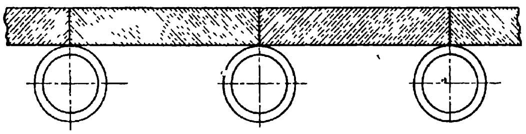

FIG. 212.—ARRANGEMENT OF BAFFLE TILES.

A considerable quantity of soot generally collects about the inclined surfaces of the superheater, etc. This must all be cleared away, as otherwise the tubes may waste away externally. The danger is increased if the soot for any reason becomes wet.

The bearer bars and other supports of the baffle tiles should be examined for signs of burning. If this precaution is neglected the whole bank of slabs may fall and, becoming wedged at the back of the stoker, cause serious damage.

In some designs ordinary firebricks are used for baffling, and in such a case fireclay must be applied very thinly, its function being not to hold the bricks together, but to prevent gases leaking through the baffling in case the bricks do not make a tight fit with each other. The back baffles occasionally rest on a shelf made by bonding a row of larger baffles with the brickwork of the wall, the purpose being to provide an adjustable seal and means whereby the top ends of the tubes may be examined.

(3) *Furnace Arches.*—The laying of any arch, whether it is an arch over an inspection door, stoker arch, or coking arch, must be done in a special manner, according to the function of the arch. An inspection arch in the wall of a boiler has to take the weight of brickwork above it. A coking arch must be very flat to throw down the heat. Such an arch cannot carry any weight. All arches must be constructed of the very best grade of firebrick obtainable.

It is essential that in all brickwork the greatest care should be taken to keep the joints as thin as possible; the fireclay in which the bricks are set should be mixed quite thin, the bricks dipped into it and rubbed to a joint. If thick joints are used the brickwork will crack and fall away very soon after fires are put under the boiler.

All bricks should be rubbed down to a smooth surface on a board, dipped in liquid fireclay, and hammered home, and on no account should they be laid with the trowel.

The lining of the furnace immediately under the arch must be so arranged that it is renewable without disturbing the arch itself; but it must be tied at various points to prevent it falling away.

A space of 1 inch must be left between the top of the arch and the lintel plate immediately above it, to permit of the free expansion of the brickwork, and every alternate brick in the end of the arch should be 6¾ inches long instead of the usual 4½ inches, in order to do away with the use of half-bricks for finishing the bonding, as these are liable to fall out and allow the flame to attack the courses behind them.

Before starting to build the arch itself, it is necessary to lay off the lines of the skew-back. While laying off the skew-back, and while laying the brick in same, use a good straight-edge the length of the arch. See particularly that the skew-backs have no lumps, bumps, or other irregularities. See that the two skew-backs are perfectly parallel, level, and in line the one with the other. Keep using the straight-edge until the surfaces are smooth and regular.

The centre on which to turn the arch should be made as follows:

Have three segments of the proper length and radius cut from 1½-inch plank. Let the distance between the two outer segments be 6 inches less than the length of the arch; place the third segment in the centre of the two outer ones. See that they are parallel with each other when nailed up. Batten the segments with 1-inch square strips, smooth and straight, and laid close together.

After the strips are well and securely nailed to segments, plane off to a true circle. When the centre is completed, set in place, being careful that the two outside strips line exactly with skew-backs. If they will not line, either the skew-backs or centre must be wrong, and should be corrected before a single brick is laid.

When the centre is set and found correct, select smooth, straight and uniform wedge brick. Have the solution of fireclay soft and well mixed. Do not use a trowel; dip the brick and push up close, tapping to place with a brick hammer.

The width of an arch is generally determined by the distance between the walls. The corresponding camber and radius may be obtained from fig. 213, which has been most carefully prepared to furnish exact sizes for the practical guidance of the engineer-chemist.

(4) *Firebridges.*—Boilers equipped with mechanical stokers are not generally fitted with firebridges. In some instances a brick wall is built in the lower half of a Lancashire boiler furnace to stop clinker and ashes from being pushed further into the flue, instead of being raked out, when the fireman comes to remove them. Water-tube boilers are fitted with firebridges only when stoked by hand.

Firebridges are found at the back of all grates fitted to Lancashire, water-tube, and marine boilers, when these are fired by hand. Locomotive boilers, and occasionally vertical boilers, are fitted with brick deflecting arches to protect the ends of the tubes from becoming overheated.

The function of a firebridge is twofold :-firstly, to stop fuel from falling over the back of the grate, and secondly, when it is incandescent, to assist in igniting the volatile gases as they leave the boiler. With regard to the latter function, various types of patent bridges have been perfected (see figs 33 and 94).

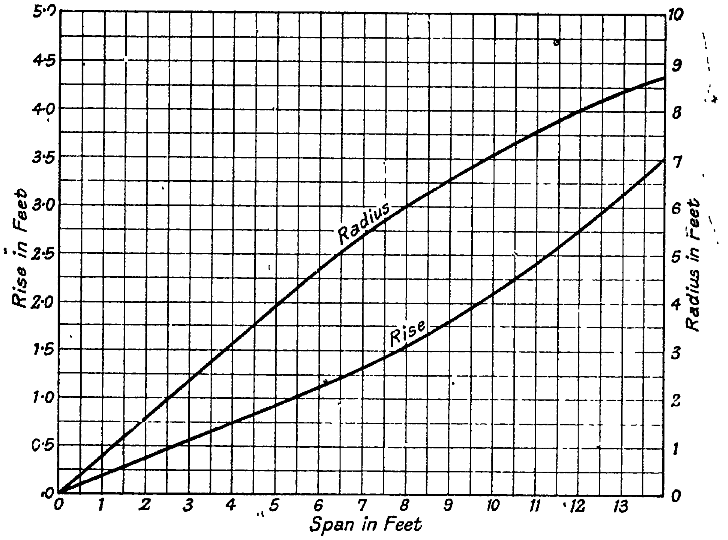

Fig 213 - Relationship between Height, Radius, and Distance between Walls for Furnace Arches

A firebridge which will prevent fuel from falling over the back of the grate, and will offer a large heating surface to the gases as they leave the grate, may be easily constructed of common firebrick. In order to achieve this object the bridge is built rather deeper and one course higher than the ordinary solid firebridge. To compensate for the reduction in flue area, due to the additional height, bricks are left out in the two upper courses to form a number of channels. It is most important to make the bridge deep, so that the gases leaving the grate may pass through and over incandescent channels of firebrick. Such a bridge is illustrated in fig. 214. The excess number of bricks used is due solely to the additional thickness necessary to make efficient channels.

In most boilers the grate is too long for the intensity of the draught, and by reducing the grate area more complete combustion can be obtained. In any case, the back part of the grate is generally only partially covered with fuel, causing bad air leaks; and an increase in the depth of the firebridge will have a beneficial effect.

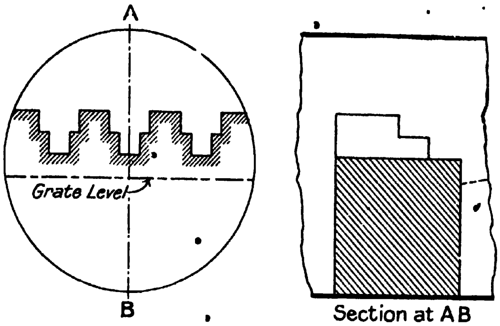

FIG. 214.—FIREBRIDGE BUILT OF ORDINARY BRICK.

As little fireclay as possible should be used in building firebridges, as when the clay becomes hard it falls away. The bricks then become loose, and when the fires are being cleaned a knock with the rake sends the bricks over the end of the dead plate into the flue.

CHAPTER XVIII

"LAYING UP"

(*a*) *Internal Precautions.*—When a boiler has been cleaned, and is not to be used for some time, special precautions are necessary to guard against corrosion.[1] Typical cases requiring special precautions are: boilers on board a ship lying up during the winter, boilers of power stations supplying residential areas and therefore having a light load in the summer, factory boilers which supply steam to machinery only used during the season (as, for instance, in meat-canning in the Argentine or sugar-boiling in the West Indies).

When the boiler has been cleaned and washed out with clean fresh water, the plates enclosing the steam space, when dry, should be painted with a wash of white zinc and kerosene. When the paint is dry the bottom man-holes are carefully put in place and tightened up, and the boiler is prepared for laying up either on the "full method" or the "empty method."

The "full method" requires that the boiler be filled to the very top with clean water. The water must be absolutely pure: in other words, it must contain no organic matter, acid impurities, corrosive salts in solution or suspension, and no solid non-corrosive matter. The boiler may be filled absolutely full by inserting a hose pipe in the top man-hole, provided that the latter is on the centre line of the boiler. If the man-hole is off the centre, as is often the case with marine boilers, or is in the end of the steam drum, as in the case of water-tube boilers, this method will only partially fill the boiler. In such cases the remaining quantity required to fill the boiler to the top must be pumped in through the check valve in the usual manner.

The pressure gauge should be disconnected, because it is fitted to the highest part of the steam space, and its removal will therefore permit all air to escape. When the water flows from the pressure gauge pipe, the pump, which has already been slowed down, is stopped.

A very small fire should be lighted—preferably a wood fire—and arrangements should be made to collect the water escaping from the pressure gauge pipe. As the water is heated it expands, and the air is expelled, together with water displaced by the expansion. The expelled air and surplus water leave the boiler with much spluttering, and therefore a small tank rather than a bucket should be provided to collect the overflow. When the top of the boiler is so hot that it is impossible to touch it for longer than five seconds, the fire should be allowed to die out. When the fire is dead, the pressure gauge should be replaced. Some authorities advocate removing the safety-valve and covering the opening with a blind flange, although they are divided on the question whether this should be done before or after the boiler is full. Should steam pressure accidentally accumulate, the absence of the safety-valve might result in disaster of the first magnitude.

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[1] *Metallic Structures, Corrosion, Fouling, and their Prevention*, T. Newman.

If the procedure outlined above is faithfully observed, there will be no space in which steam can condense and form a vacuum which might result in the admission of air.

The boiler is now full of water from which the air has been expelled.

As the " full method " requires constant and minute watchfulness while the air is being expelled, some mechanics do not completely fill the boiler, but bring the water to boiling-point. When this is done, steam accumulates in the boiler. Later the steam condenses, and a partial vacuum is formed. A certain area of the shell plates enclosing the steam space is therefore exposed to vapour, although no oxygen is present. Also the boiler is constantly subjected to the pressure of the atmosphere. In this connection it should be remembered that boilers have collapsed under such pressure. It is absolutely essential that no air should collect in any pockets, and that all fittings should be absolutely tight.

The " empty " method requires that the inside of the boiler be bone dry. After the boiler has been drained, the water still remaining is scooped out into buckets, and the shell is vigorously mopped. When this has been done, fires are lighted in two fire-boxes, similar to those used by railway watchmen, or in two large buckets suitably perforated. The fire-boxes, or buckets, are then hung, or stood, in front of the boiler, so that the air passing through the boiler, and following the course normally taken by the products of combustion, will be warmed sufficiently to evaporate all the remaining moisture inside the boiler without any damaging effect upon the interior surface.

When the plates no longer feel chilly to the hand, the bottom man-holes are put in position. A brazier is prepared, containing pure charcoal and nothing else. On no account must any substitute material be used, for the whole purpose of introducing the brazier will be defeated unless the fuel is absolutely free from sulphur and volatile products. When the brazier is well alight, it should be hung, or set, inside the boiler, and the top man-hole put in position. The oxygen contained in the air inside the boiler is reduced to carbon dioxide, and because this can promote corrosion in the presence of moisture it is essential that the boiler should be perfectly dry inside.

This method is not so easy to work as the " full " method, but it is widely adopted in the Royal Navy. The " full " method finds favour with engineers in the mercantile marine and ashore.

When a boiler is laid up on the " full " method, it is good practice to introduce about 3 pounds of soda before filling. By this means corrosion due to possible undetected acidity in the water will be prevented. Slightly alkaline water does not cause corrosion, but excessively alkaline water is bad because the brass fittings corrode. Ammonia salts must on no account be used to create alkalinity, because these attack iron and brass.

In very cold climates fires should regularly stand in front of boilers out of use, because frost has a bad effect on steel. Steel which has not been protected from frost is liable to fail under high stresses. Wherever freezing temperatures are reached, all fittings must be wiped dry internally, as the "full" method cannot, of course, be adopted. Water on freezing expands before it contracts, and the force thus exerted is sufficient to burst any of the fittings. As very little moisture is held in suspension, boilers in dry northern climates may be left open provided they have been thoroughly dried.

When a boiler is laid up on the "empty" method, the engineer-chemist must verify by a most thorough personal inspection that it is absolutely empty and

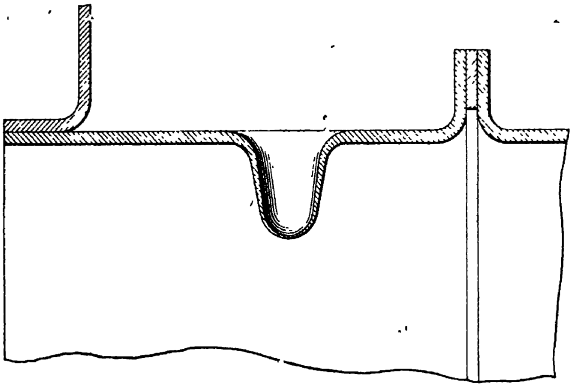

FIG. 215.—BULGE IN FURNACE DUE TO OVERHEATING.

absolutely dry Tools or other gear left on the furnace will cause overheating when the boiler is again put in operation, with results shown in fig 215, if the metal is of special quality, and so does not fail under the distortion.

If the metal fails, an irregular collapse or explosion takes place.

The engineer-chemist's choice of the "full" or the "empty" method of preserving his boilers when laid up will depend upon the conclusions to which his experience and chemical research have led him. One school is inclined to believe that carbon dioxide is the dominating influence in producing corrosion. This view is entitled to respect, although there is great weight of authority for the opposite opinion that oxygen alone is the deciding factor.

(*b*) *External Precautions.*—It is usual to attend to the inside of a boiler first, so that it may be closed up as soon as possible, to prevent corrosion commencing.

The outside of the boiler will receive attention according to its construction. Lancashire and similar boilers will have been thoroughly cleaned in preparation for external inspection, so that a periodical examination, to make sure no moisture is forming, will be all that is necessary.

Factory boilers, when laid up for any length of time, may with advantage receive two coats of oxide of iron paint. If, however, the plant is in the tropics, an application of good red lead paint will prove to be a better protection against the ravages of a damp atmosphere. All paint that is applied to the outside of a boiler may, of course, be mixed with ordinary vegetable oils. It is only for use inside the boiler that these oils are forbidden. The whole external surface of a boiler will, of course, not be painted, but only that which is subjected to atmospheric corrosion. The surface to be painted will vary to a considerable extent, because some boilers are properly lagged, whilst others are covered with poor composition which, if moist, offers every facility for corrosion to take place.

If any lagging has been removed for the purpose of inspecting the boiler, it is a good plan to leave it off and give the boiler shell a good painting. The lagging can be replaced when the boiler is ready for work again. In any case, the lagging will bind with the steel plates much better if it is put on when these are warm.

As a matter of precaution, it is good practice to remove all brickwork in the neighbourhood of seams, riveted joints, and fittings, so that the chances of corrosion may be reduced to a minimum. Boilers that are properly housed, or boilers on board ship, may be protected against excessive cold by making sure the boiler space is weather-proof. Of course, the engineer-chemist will not allow every shower of rain to wash down the boilers, when this can be prevented by covering the fiddley tops or shutting a skylight or mending the roof.

When boilers are to be laid up for any length of time, the firing floor should be thoroughly cleaned. Boilers are generally cleaned before "laying up," but an accumulation of ashes and soot is frequently left where it was dumped when cleaning was in progress, so that a stranger may be excused if he thinks the boilers have only just been closed down. It is not sufficient to clean the outside of the boilers only, but all conduits under the floor should be freed of ashes or other dirt, and the pipes cleaned and examined for corrosion and leaks.

In many instances such "laying-up" affords the engineer-chemist his only opportunity to undertake large repairs, and if he has kept a careful diary, recording the repairs necessary whenever he has noticed faults, the plant should be in good working order when the time arrives to put the boilers once more in operation.

It is a common sight to see unburnt fuel and clinker lying on the grate of a boiler long after the boiler has stopped working. Such negligence is frequently characteristic of the general management of the plant.

Special precautions are necessary if boilers are subject to flooding or to intense cold. Intense cold has a serious effect on steel plates, and whenever possible the boiler house or stokehold should be closed, so that the temperature of the atmosphere shall not readily penetrate into this space.[1] It is good practice to keep the temperature of the boiler room as uniform as possible, and this may easily be accomplished by standing a small brazier in front of every boiler. In cold climates it is of great importance to make perfectly sure that no condensed steam remains in any fittings, valves, pipes, or other vessels.

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[1] *Trans. North East Coast Inst.*, August, 1915.

The bad effect of dampness has been mentioned in other connections. All boiler houses which are situated near rivers, or are otherwise liable to flooding, should, of course, be so designed that there is no fear of the water reaching the boilers. This precaution is very often omitted, and there are plants in existence which suffer very badly from water trouble during the winter months. Main flues which run under the ground must also be protected from flood.

Modern practice, especially in the case of water-tube boilers, is to place the unit above the ground-level, so that ash trucks may conveniently be run under the boilers for the purpose of removing the ashes from special shoots built under the boilers. With such installations the danger of flooding is remote. There are a very large number of boilers on the ground-level, or even below the ground, and it frequently happens that water collects in the stoker pits. When boilers so located are laid up for any length of time, and the moisture is no longer evaporated and the brickwork kept dry by heat radiated from the grate, special care is necessary. Boiler houses built on soft ground suffer more in this respect than those erected on a solid earth, because the weight of the boilers apparently assists in pressing the moisture out of the surrounding substrata.

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SECTION VI.—OVERHAULING AUXILIARY PLANT

CHAPTER XIX

AUXILIARY APPLIANCES

THE auxiliary plant should receive the same painstaking attention as the boilers themselves. Although a defect in the auxiliary apparatus may not lead to a stoppage of the works, it is quite likely to cause great inconvenience, and may possibly be responsible for an explosion.

(*a*) *Superheater.*—The defects of superheaters depend to a certain extent upon the position of the apparatus, which may be at the end of a Lancashire boiler, high up on a water-tube boiler, inside the tubes of a marine or locomotive boiler, or entirely outside the boiler structure.[1] [2] Fig. 216 shows a "Unit" patent superheater as fitted to a water-tube boiler.

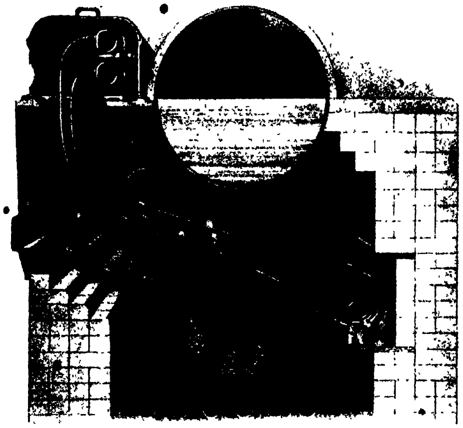

FIG. 216.—"UNIT" SUPERHEATER FITTED TO A WATER-TUBE BOILER.

In the case of a Lancashire boiler, the brickwork covering should be removed, if necessary, to enable a thorough cleaning and inspection of the superheater to take place. The tubes of the superheater should be properly cleaned with an air blast—in no circumstances must steam be used for the purpose—and thoroughly scrubbed with wire brushes. The header and the necks of all the tubes will also be examined for signs of corrosion. The tubes are generally solid drawn seamless steel tubes expanded into steel headers, but the joints should be examined for leaks. The interior of the tubes may be coated with scale due to priming of the boiler, and in such cases the bend at the bottom may be full of sediment. If a superheater shows serious signs of scale or external wasting, one of the tubes should be withdrawn and cut through in order that the appearance of the interior may be thoroughly inspected. In view of the risk that an explosion may result in the near future if proper precautions are not taken in this respect, the loss of a single tube is a cheap price to pay for the data necessary for a correct judgment concerning the condition of the superheater.

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[1] "Large Locomotive Boilers," G. S. Churchwarden, *Trans. Inst. Mech. Eng.*, 1906.

[2] *Superheating on Continental Locomotives*, E. Sauvage, Paris.

If the ends of the tubes are fitted with caps or plugs, an internal inspection should be made at least twice a year, but if the superheater is of the large cover type, requiring the withdrawal of many bolts before the cover can be lifted, the interval between successive examinations may be extended to a year.

Accumulation of soot and burning of the lower ends of the tubes are common faults. Special attention should be given to the cleaning, particularly round the expanded joints round the boxes (see figs. 184 and 185)

It is very advisable to test the superheater with hydraulic pressure equal to the original test pressure in order to make sure everything is in order.[1] The pressure gauge and the safety-valve should be removed, cleaned, and tested. The safety-valve must be steam-tight and easy to work, before it is replaced.

It is of the utmost importance that the superheater drain should be in perfect working order, and that the drain pipe should be absolutely clear.

In some cases it is necessary to flood the superheater when starting a boiler in order to avoid burning out the tubes All units which are worked in this manner must be fitted with a safety-valve

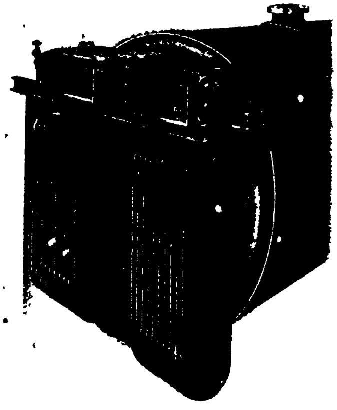

FIG 217.—LANCASHIRE BOILER FITTED WITH COMPOUND TUBE "UNIT" SUPERHEATER.

When laying up a boiler it is generally advisable to flood the superheater, but this will depend on its position and the general conditions under which the plant is operated (see Chapter XVIII).

Trouble is often experienced with large superheaters which have been fitted to small high-pressure boilers in the belief that the larger the superheater the more efficient will be the superheating of the steam. The reason for the trouble in such a case is not far to seek. A pound of steam at 10 pounds gauge pressure occupies 7·6 cubic feet as compared with the 2·56 cubic feet occupied by a pound of steam at 160 pounds gauge pressure. It is obvious that if the same number of tubes are employed in both cases, the speed at which steam passes through the superheater tubes at 160 pounds gauge pressure will only be one-third of that attained by steam at 40 pounds gauge pressure—assuming the evaporation to be the same in both cases. When, therefore, a greater number of tubes are employed than are strictly necessary for the volume of steam to be dealt with, the flow of steam through the tubes is uneven and, the volume not being sufficient to supply all the tubes equally, those having the lowest steam speed quickly burn out because the steam in them is superheated to the point of dissociation.

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[1] "Effect of Repetition Stresses on Materials," Prof. F. C. Lea, *Engineering*, vol. 115, p 217.

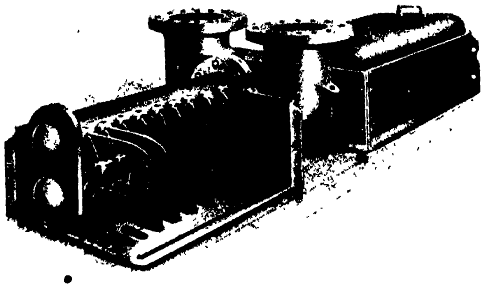

FIG. 218.—REPLACEMENT OF TUBE ELEMENTS BY SHORT-CIRCUITING LOOP IN A "UNIT" SUPERHEATER.

When water in the form of steam is passed over hot iron, it splits up into its component parts, and the oxygen combines with the iron, resulting in the quick reduction of the tube surfaces into oxide of iron.

In special cases where a high degree of superheat is required, the tubes must be specially designed for this purpose. Fig. 217 shows a Lancashire boiler fitted with patent compound tube "Unit" superheater.

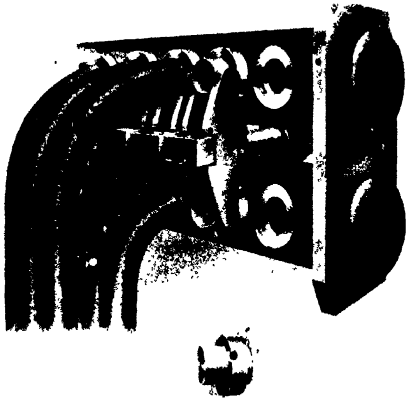

FIG. 219.—EMERGENCY STOPPERS REPLACING TUBE ELEMENTS AND SECURED BY THE SAME CLAMPS AND BOLTS.

A superheater should be designed so that the degree of superheat may be regulated as desired. Fig. 218 shows the replacement of tube elements in a "Unit" superheater by short-circuiting loops—a simple and effective means of controlling the degree of superheat.

Should a tube burn out whilst the boiler is at work, it must be possible to withdraw or blank off the damaged tube. Fig. 219 shows a "Unit" superheater header with emergency stoppers replacing tube elements, and secured by the same clamps and bolts.

(*b*) *Economizer and Gear.*—The usual installation consists of a "Green" type cast-iron tube economizer of the required number of tubes, arranged either in series or in parallel.

An economizer is really a continuation of the boiler, with the one great difference that while the boiler must add sufficient heat to the water to convert it into steam at the working pressure, the economizer must add only such heat as can be absorbed by the water without conversion into steam. By thinking of the economizer in this way we get clearly in our minds the vital point that steam must not be formed in the economizer. If steam does form, water-hammer will occur.

Boilers attached to the ordinary factory generate steam during the daytime only, and fires are banked during the night. When the fires are shaken up in the morning, the boilers are generally full of water, having been pumped up to "full glass" the night before, so that the feed valve is not opened until the factory commences working. If hot gases pass through the economizer during the night period, when the apparatus is not working with the boiler and serves merely as a container for water, this water will soon be raised to boiling-point. In order to avoid water-hammer, therefore, the by-pass dampers must be eased in the evening, so that only sufficient heat will reach the economizer to keep the tubes warm. In the morning these dampers must not be fully opened until the feed pumps are put in operation. If steam forms in the economizer, the tubes may become burnt, and if comparatively cold water is allowed to take the place of the steam, the tubes are offered every inducement to leak, and may also possibly crack. Fig 220 illustrates some defects in economizer pipes.

The piece of pipe at "A," was blown out. It had probably been previously weakened by overheating, as already described "B" shows a piece of economizer pipe which was broken owing to the excessive thickness of scale in its interior. The difference in expansion between the scale and the metal of the pipe is almost as great as that developed when water commences to freeze. Economizers must therefore never be left full of water during the winter if not working. A piece of pipe which has become severely wasted under the scale is shown at "C."

When an economizer is to be cleaned the procedure is somewhat similar to that adopted when preparing a boiler for cleaning. The economizer must first be emptied, but before this can be done the by-pass dampers must be opened and the economizer damper shut. When the economizer has had time to cool, the water will be run out through the drain valve. It is just as important with an economizer as with a boiler that the cooling and emptying should be a very gradual process. It has already been stated that if the installation is below the ground-level all manœuvring valves should be fitted with extended spindles. Before running the economizer empty, the lever weighted safety-valve must be tried, and if there is no pressure the valve must be removed so that air can displace the water when the latter runs out. All caps can then be removed from the top boxes, and all the inspection doors from the bottom headers.

Whilst this work is going on, the cleaners will remove all the soot from the pit under the tubes. This is a tedious job, and in order to save time and labour some firms have a system of vacuum pipes with branches for couplings at the inspection doors. Sometimes the system is an extension of the ash removal plant (see Chapter IX). In other cases a special plant, as manufactured by the British

Vacuum Co., Ltd., is installed. Fig. 221 shows a vacuum pipe system for a typical boiler plant.

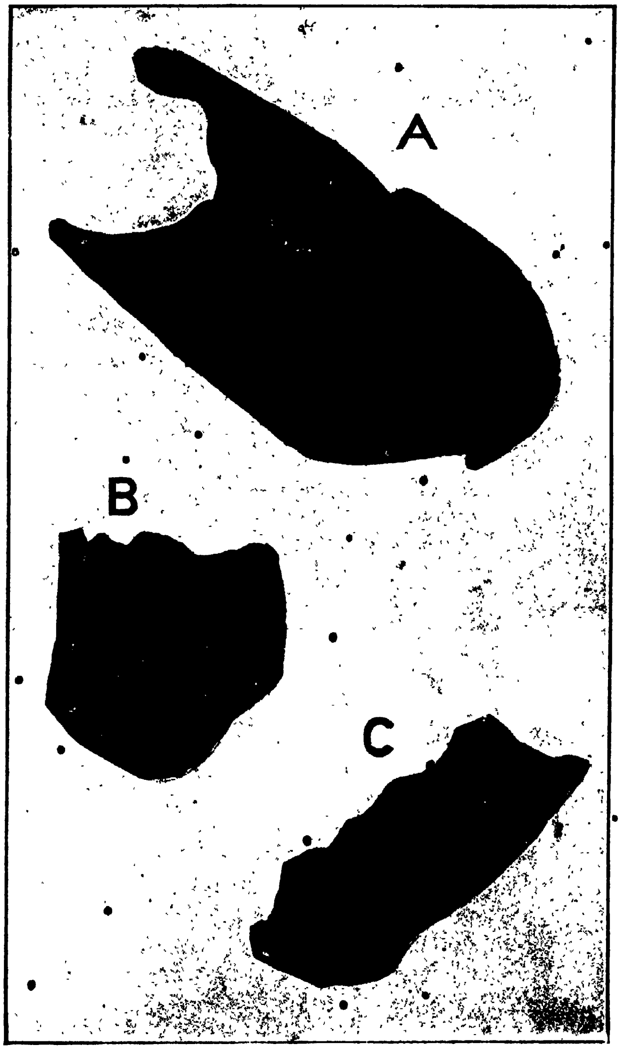

FIG. 220.—DEFECTS IN ECONOMIZER PIPES.

A flexible hose, fitted with a special nozzle which cannot choke when thrust into a heap of soot, is attached to the nearest coupling, and one man can clean all the flues, as shown in fig. 222.

This is a truly scientific method, as compared with the usual manual labour, involving the trundling of a series of overloaded wheelbarrows, which leave a trail of soot all the way to the ash heap.

When the soot has been removed from the flue chamber, from the bottom soot pit, and from around the pipes and boxes, all the tubes that can be reached should be brushed down with wire brushes, and the scraper gear properly cleaned. If the gear is covered with solid matter a long chisel bar must be used.

For thorough examination of the economizer there must be access to each end in the flue, and at least on one side.

If there is no special provision for passage along one side of the apparatus, large openings with doors should be placed near together in the side walls. The vertical pipes frequently become seriously weakened by wasting at the bottom ends externally. Complete flue examination is therefore very important.

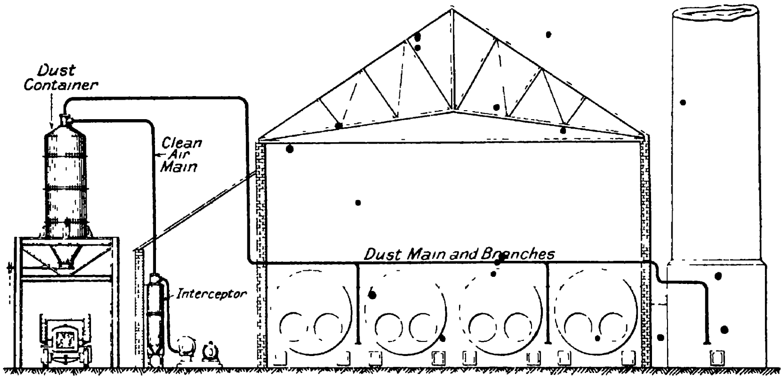

FIG. 221.—APPLICATION OF FLUE-CLEANING INSTALLATION TO A LANCASHIRE BOILER PLANT

In some cases time does not permit of the removal of all the caps. Under such circumstances at least one cap should be removed in each section

Failing complete opening, the pipes opened should be those not recently opened for inspection. It is advisable that the exact position of each pipe opened be shown on a plan kept by the engineer-chemist, and that on this plan the date of opening be entered. The object of this record is to enable the engineer-chemist to have all pipes opened and cleaned in regular order, and to avoid the same pipes being repeatedly opened and other pipes not opened. The interior of the pipes should be thoroughly cleaned. All the bottom boxes should be opened and cleaned.

The safety-valves, blow-down cock or valve, and inlet and outlet valves should be taken adrift, cleaned, and overhauled at least twice a year. The best practice is to take the mounting into the repair shop and do the work there.

In the case of economizers fitted with external caps held in position by internal bolts, all caps should be removed once a year, and the bolts carefully examined, as these are liable to waste both at the head and in the body. If, for any reason, all cannot be examined at the same time, a few should be removed from time to time until the whole have been inspected. Economizer tubes require the special attention already prescribed for the inside of tubes of water-tube boilers situated immediately over the fire.

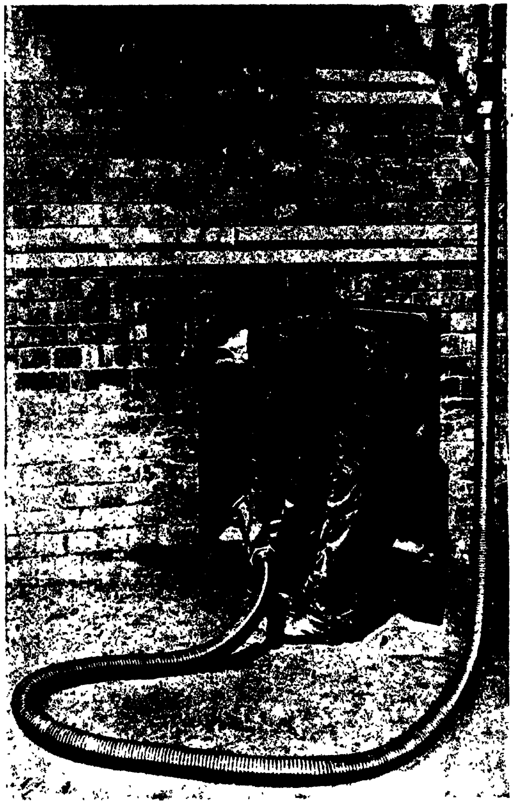

FIG. 222.—CLEANING FLUES WITH A SHOVEL-TYPE HOSE, AERATOR NOZZLE

The internal examination down the pipes is useful to determine the amount of ncrustation, but, as a rule, no reliable determination of the extent of corrosion can e made in this way, and many of the pipes cannot be got at externally for sounding r for callipering in case of external corrosion. It is, therefore, advisable, in some ases, that the economizer be subjected to hydraulic test to about twice the safety-alve load, and where serious internal corrosion is suspected it may be advisable o break up one or more pipes for special examination.

The various parts of an economizer which are specially liable to corrode are shown in fig. 223.

When burning fuel containing a large percentage of volatile matter, it is of special importance that the temperature of the water as it enters the economizer should be not lower than 110° F. If this temperature is not maintained the gases will condense and form tar, which, mixing with the soot, will form a sticky mass beyond the power of scrapers to remove.

When boilers are fitted with steam jets the economizers must be carefully watched, because very little of the steam from the jets is split up into its component parts. Not being decomposed, the steam condenses to form water, and as much as a ton may be formed per boiler per hour. Most of this collects in the economizer chamber.

The expansion bends between groups of economizers should be taken down, and the bottom and top boxes sighted, or tried with a steel wire drawn right through and held taut.

Cast-iron economizers have been ruined by faulty erection, and because cast-iron cannot be sprung to any extent, joints leak from the very first if the economizer is out of line An economizer that is really in line, and the pipes of which are dead plumb, gives no trouble in this respect.

The safety-valve overflow pipe should be as straight as possible. The safety valve itself should be provided with a spout under which is the large cone attached to the pipe. A closed, or bolted, joint connection is inadvisable, because the pipe is often not straight, or it is blocked with cinders, in either of which cases the water cannot get away, and may cause damage. In the open arrangement the water will overflow if it cannot escape otherwise

Economizers should always be situated above ground-level, so that they can be kept thoroughly dry, and if the main flue is constructed in a proper manner the slight rise necessary to carry the gases through the centre of the economizer will make no difference to the draught.

Steel-tube economizers were described in Chapter VI (p. 87), where it was stated that, due to their comparatively recent introduction, an adequate quantity of reliable information is not yet available concerning their deterioration. Such information as is to hand shows that pitting and corrosion due to oxidation of the steel must be guarded against This type of economizer has been introduced because, with the very high working pressures in vogue to-day, a certain element of fear has crept into the minds of some engineers with reference to the possibilities of failure of cast-iron. Deposits of grease have not given the serious results that might have been expected, judging from the serious effect which the thinnest film of grease produces on the heating surfaces of boilers. The danger of burnt tubes is small unless the baffling arrangements are faulty, but this depends to a certain extent on how the water circulates through the tubes.

In all cases the caps should be removed once a year, even though the boiler is fed with pure distilled water. If any corrosion is seen round the necks of the tubes or on the inside walls of the header, small strips of zinc, covered with amalgam, should be fixed on the outlet side of the header.

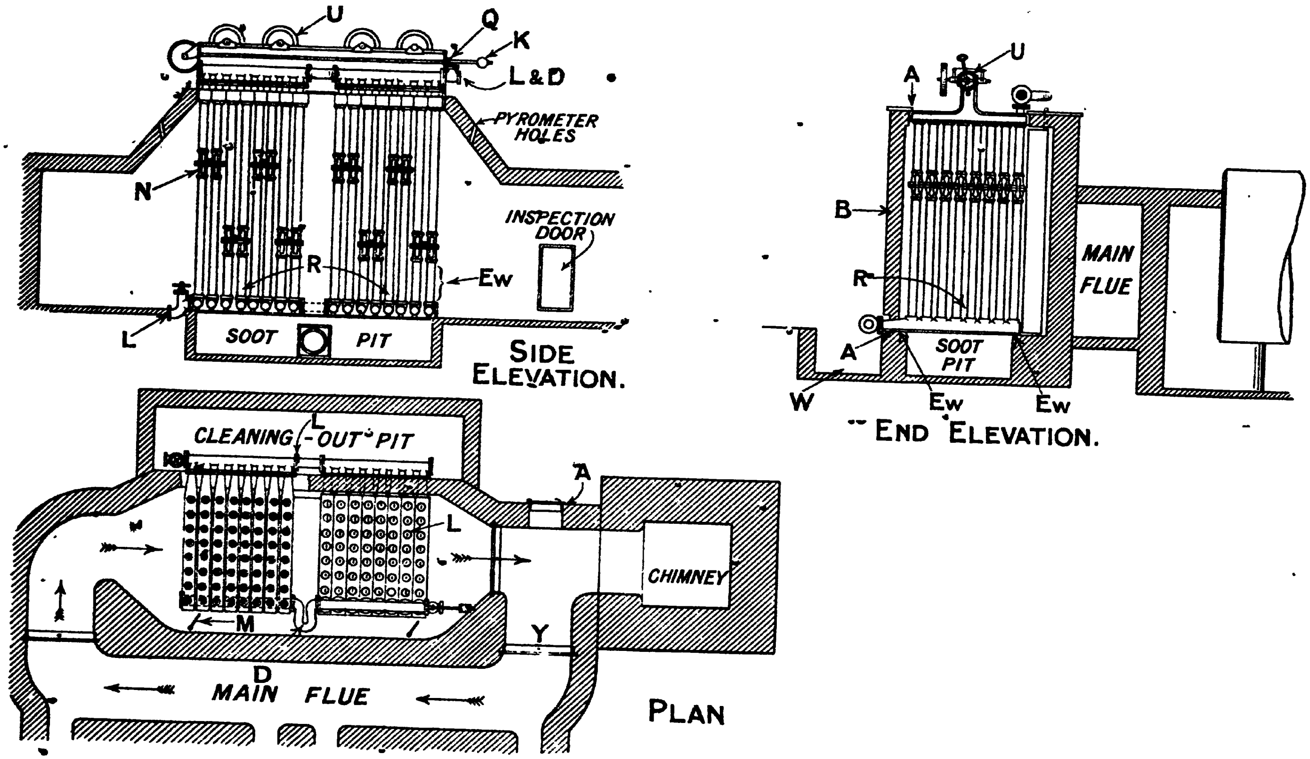

FIG. 223.—GREEN TYPE ECONOMIZER OF 128 TUBES.

A = Air Leakage.
B = Cracked or Broken Brickwork.
D = Deposit on Water Side.
Ew = External Wasting.
K = Overloading.
L = Leakage.
M = Deflectors Open and Gases Short-Circuiting.
N = Scrapers Failing to Scrape Full Length of Tube.
Q = Rust and Deposit Causing Sticking.
R = External Deposit of Flue Dust.
U = Lack of Lubricant.
W = Ingress of Rain.
Y = By-pass Damper Open.

On account of the higher pressure at which economizers are operated when they are incorporated with water-tube boilers, extra care is required when making the joints, and cleanliness is of great importance. If the outside of the tubes cannot be cleaned periodically with a soot blower, a long iron chain should be drawn over each row of tubes to make sure that no soot has caked hard between the tubes.

(c) *Pumps, Meters, and Injectors.*—It has already been pointed out that all steam wasted in the boiler department reduces the quantity that the engineer-chemist can supply to the factory. He should therefore exercise the strictest economy in this respect, and keep the steam consumption of the auxiliaries under observation.

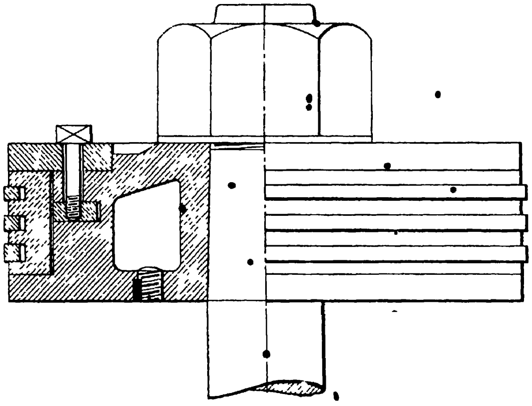

FIG 224 PISTON FITTED WITH ORDINARY RINGS

Pumps are often in a bad state of repair and, as they generally exhaust to atmosphere, they consume far too large a percentage of the total steam generated The reasons for this waste are leaky steam pistons and faulty valve gear. The pistons of pumps, and especially of small reciprocating engines, are often fitted with a single deep ring which is far too stiff, and, being fitted with a large brass tongue piece, does not follow the bore of the cylinder, especially if this has become barrelled. In such cases the deep piston ring should be taken out, and two or three small ordinary Ramsbottom rings fitted, with a packing ring to make up the necessary thickness. A piston fitted with a number of small rings is shown in fig. 224.

The conversion can be effected by the repair shop staff.

The engineer-chemist should keep a description of every auxiliary machine under his care, with a sketch of the steam and water piston rings, brass glands, and other details. This information may conveniently be set out in the form shown n Table VI.

TABLE VI

Pump Information Sheet

Works reference number ....
Function and situation ....
Makers' name and number ....
Description and type ....
Diameter of cylinders ....
Stroke ....
Normal number of strokes per minute ....
Steam pressure ....
Back pressure ....
Horse power ....
Steam consumption per hour ....
Steam per I.H.P. per hour ....
Working hours per week ....
Delivery pressure ....
Discharge per hour ....
Efficiency ....
Steam pipe diameter ....
Exhaust pipe diameter ....
Diameter of piston rod ....
Diameter of glands ....
Remarks ....
....
....
....

When a pump is to be overhauled, it is not necessary, if proper records are kept, to open it up to take the sizes of the piston rings, glands, piston rod, valves, or other details. These are made a certain number at a time, and put in the store. When the time comes for its overhauling, the pump is disconnected and taken to the repair shop. As the fitters take the pump adrift, the various parts that require skimming up in the lathe or reboring are cleaned and given to the machine men. When the fitters have taken the pump or engine adrift and have cleaned those parts that are not worn, the new parts, such as piston rings, neck bushes, or valves, are tried in position to make sure that they are a good fit. The various parts sent to the machines will now be ready, and the re-erection can commence. There will be no waiting while a casting is made before the piston rings can be turned. By thus arranging matters in advance the pump can be sent back to the pump house, coupled up to the range, and started once more at work with a minimum of delay.

Rods become scored for several reasons, but with good management there need be no scoring at all. When scoring occurs, it is generally the packing that is at fault, whether the part affected be a stop-valve spindle, expansion or other steam gland, or the piston rod of a reciprocating engine. These rods become particularly badly scored.

There are on the market a large number of excellent packings which are sold neatly wrapped in paper and contained in cardboard boxes. If taken out, one end allowed to dangle on wet ground covered with ashes, and the other end pressed against a dirty wall or laid on a soot-covered valve in order that a short length may be sheared off with a blunt knife, the packing, which is generally soaked with cylinder oil and graphite, will pick up all sorts of grit. When a gland is packed on the workshop bench the packing is often thoroughly turned in a mixture of spilt emery powder and steel or iron filings, which remain in the packing, and score the rod when in position.

A clean piece of wood and a sharp packing knife will remedy all this, and save many rods from becoming unnecessarily scored

Another cause of trouble is the careless tightening of glands, so that they are not square to the rod, and consequently wear unevenly. When the stuffing box is repacked, and the gland set square to the rod, the clearance is not equal, and one side of the piston rod will become very hot, burning the new packing in a short time, and steam will escape as badly as ever. Such glands, if not rebushed, must be tightened up with the aid of testers that is, set for an equal clearance round the piston rod, irrespective of being square to the rod. These items may seem very petty, but a faulty gland can be rebushed only by disconnecting the cross head, raising the piston rod, and slipping off the gland, all of which costs time and, therefore, money, which can easily be saved.

Further, a scored rod must be skimmed up in the lathe, or ground in a grinding machine, if the repair shop contains such a refinement, and a perfectly new set of neck bushes and glands is necessary, which is even more expensive.

Ordinary asbestos packing is satisfactory for stop-valve spindles and parts which are not moved frequently, but for reciprocating engine or pump rods a good packing, such as Beldam, or Ferguson and Timpson's Thistle packing, may be used with advantage.

In packing a valve with soft packing, be it a steam or water packing, the secret of success is to cut the packing so that the ends butt hard together. It is good practice to use packing a size larger than the stuffing-box size. For example, if the clearance between the piston and stuffing-box is $\frac{1}{2}$ inch, use $\frac{5}{8}$ inch packing, because the heat of the steam or water will cause some of the cylinder oil or tallow to leave the packing. If the neat size is used, it will generally be found that the gland can be screwed right home after the pump or engine has been running a day. In that event the machinery must be stopped to insert an extra turn of packing.

Soft packing is cut the full circumference of the rod, and the ends securely tied with any soft twine. Ordinary string will serve the purpose so long as it is not of the hard superior corded variety. The packing is flattened by tapping with a clean hammer on a clean board. After this treatment it will easily slip into the stuffing-box, and make a tight butt.

The water piston, or "bucket," as it is frequently called, may also be a cause of inefficient working. The piston rings wear slack, due to gritty particles in the feed water, and are reduced from $\frac{5}{8}$ to $\frac{3}{8}$ inch in thickness, so that the piston passes more water than it displaces. Frequently the rings have become covered with a mixture of clay or slimy dirt, and, instead of floating nicely as they should, the piston and rings form one solid mass. Various makers employ different methods for packing the water pistons, from hemp-packed buckets to leather cups filled with special packing and alternating with soft metal rings.

The usual type of piston, and that which gives the best results, is similar in construction to the steam piston, and is fitted with ordinary rings made of vulcanite or patent fibre. The rings can easily be fitted, are not hard to procure, and any ordinary fitter understands them, which is not always the case with patent packing.

The inlet and outlet pump valves must be thoroughly examined and ground in, or renewed, if necessary. Pumps may be fitted with a series of small valves arranged concentrically, as in the Weir pump. This is by far the best arrangement, as it provides for a large inlet or discharge area with a small lift.

In many cases disc valves, made of some very tough copper alloy, are used. Especially in the case of condensed steam, this type works extremely well, the only attention required being an occasional cleaning with a rag dipped in mineral oil, such as paraffin or petroleum.

The lift of the valves is generally regulated by a set screw and locking nut in the valve chest cover. The set screw should be very carefully adjusted. Makers of repute often use a thin brown paper joint painted with red lead paint for the valve chest cover. When the pump is closed up after repairing, an insertion joint $\frac{1}{16}$ inch thick is often used, because no paper is handy or the fitter is lazy. The direct result of this in the case of a pump fitted with a large number of small valves is that the lift is increased out of proportion to the diameter of the valves, and the pump hammers. In such a case the set screw in the valve chest cover must be adjusted to make up for the increase in thickness of the joint. This is very often overlooked.

Reciprocating pumps are of many types, and it is only possible here to offer suggestions for treatment of their commoner ailments. Some of these have already been mentioned in Chapter VII.

Sticking of the valve gear is quite common, and in order to induce the pump to work, the exhaust valve is often screwed down until it is only open a couple of turns. This is quite permissible as an emergency measure to keep the pump running until the stand-by set has been warmed up, and is in operation. Under no circumstances, however, should this condition be tolerated for any length of time. The object in partially closing the exhaust valve, especially in the case of condensing pumps, is to bring the exhaust pressure nearer to that in the cylinder, so that the shuttle valve may float. The fact that the pump sticks is evidence that the small slide valve or auxiliary control is not steam-tight on the back of the main or shuttle valve. When it has been bedded on to the back of the shuttle valve, the small slide valve must be relined with the valve spindle, but this is generally forgotten. A thin brass liner pinned on to the back of the slide valve is all that is required to prevent the valve spindle from being bent. All main valves should be an easy fit when cold, and the auxiliary slide valves should be pulled up and down by hand, and not tried with a lever. If a lever has to be used when they are cold, they will be too tight when expanded, due to the temperature of steam. When a newly started pump sticks at either end of the stroke, the trouble is generally due to the fact that it is not yet properly warm and that condensed steam collects at the back of the shuttle valve, preventing it travelling the full stroke. As the auxiliary valve nearly always moves with, or in a definite relation to, the main valve, the initial steam opening is insufficient to balance the pressure and to move the main valve.

Feed pumps occasionally emit queer noises, which range from an ear-splitting shriek to a low protesting groan. The reason is that the steam piston rings either are too tight, or have sharp edges because they were not rubbed over with a file before being fitted to the piston. In either case the noise is due to friction caused by lack of lubrication, and the remedy is not to use a copious supply of cylinder oil. Some pumps require a little oil, and all pumps can, with advantage, be treated to a little now and then, but there is no sense in using unlimited quantities, because it is all carried away with the exhaust steam, which is thereby rendered unsuitable for use in a contact feed-water heater.

If a pump persists in attracting attention, then its call must be answered. A shallow water groove cut in the centre of the piston rings and running right round the circumference will often stop the noise.

When very high pressure steam is used, a series of radial holes can be bored through the rings, but if this is done the upper and lower surface of the rings must be scraped up, and the body and cover of the piston must be similarly treated to prevent any steam from leaking through.[1]

Most pumps are fitted with a liner in the steam and water cylinders. In the case of the water cylinder the body of the pump is generally of cast-iron, and the liner of gunmetal. Corrosion, due to acid in the water, hastens the galvanic action between the two dissimilar metals. The gunmetal liner no longer fits tight in the cast-iron body, and some of the water, instead of leaving through the discharge valve, just flows from one side of the piston to the other *via* the annular space between liner and casting. The liner cannot move, because the cylinder cover keeps it in position.

Another matter requiring attention arises in connection with feed pumps made of cast-iron, which have a separate gunmetal or brass valve chest secured by a large number of steel studs. The steel studs corrode as a result of galvanic action and of the corrosive properties of the water being pumped. When some of the studs are weakened, so that the remainder cannot take the load, the valve chest parts from the pump. In view of the fact that the ability to keep boilers running often depends on the continuous working of a single feed pump, the studs should be carefully and frequently examined. Several instances of breakdown from this cause have come to the writer's knowledge within the last five years. There is a growing tendency under the stress of modern conditions to sacrifice safety to cheapness.

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[1] *Lubrication of Locomotives*, E. L. Ahrons.

The overhauling of the water meters should be undertaken by a skilled mechanic attached to the workshop, because most meters are of the pressure type, and therefore of heavy construction, requiring engineering tools for the work. The recording mechanism seldom goes wrong, unless the cover protecting it is removed or becomes indented due to ill usage. The reciprocating parts will become slack from wear, and if the meter registers incorrectly when tested, as explained in Chapter XIV, it must be opened out for inspection.

In the case of piston water meters the piston rings may be worn or wedged tight in the body of the casting. Boilers supplied with water from a pond frequently use as much water as the pond can furnish, especially in the summer months. As the water in the pond becomes low, a considerable quantity of sediment and clay is taken into the pipe system. Some of this finds its way into the water meter and clogs the piston, so that the rings no longer float, but form a tight joint on the cylinder.

In those meters in which the direction of flow is reversed by a valve or cock, it is essential that the valve or cock should be supported by a small set screw and locking nut. Otherwise the constant rotation of the valve or cock will tend to grind it hard into the shell, and the momentum of the falling weight will not be powerful enough to move it through the required angle. When the cock or valve becomes slack, due to wear, it cannot take up a new position if it is supported by the set screw underneath. The valve or cock must be ground in and carefully adjusted so that it is leak-tight, and yet not so tight that the friction is greater than the driving mechanism can overcome.

The chief trouble experienced with injectors arises when they are worked for long periods with water containing gritty impurities. In that case the throat of the brass cone (1, 2, 3, 4 in fig. 71) becomes enlarged, and the action of the apparatus is consequently irregular. In the Gresham Patent Self-Acting Restarting Injector the cones are easily withdrawn for examination or cleaning by unscrewing the top and bottom caps. Sometimes the cones are found covered with scale, and, if so, they should be soaked in a solution composed of one part muriatic acid to ten parts of water. The scale can then readily be removed. If excessive scale is allowed to collect on the cones, the injector will, after a time, overflow.

Leaky suction connections prevent the efficient working of injectors. The water piping should be tightened up, and the spindle of the water-regulating valve carefully packed. The suction pipe may be tested for leaks by inserting a plug in the end of the pipe and blocking up the overflow branch of the injector with a blank flange. If steam is then turned on, any leaks will be indicated by escaping steam. If the injector lifts the water, but on being regulated fails to force it into the boiler and spits hot water and steam, either there is a leak in the suction connections or the steam supplied is wet. A pulsating action, or failure of the apparatus to force all the water received into the boiler, indicates either an inadequate supply of steam or a choked delivery pipe. In the former case the steam supply is probably being tapped for other purposes. Either sediment or a defective non-return valve may be responsible for trouble in the delivery pipe.

Where the water pressure is variable—and this is frequently the case where the injector is connected to town water mains—irregular working will result. Similar consequences follow if the steam is super-saturated, or is supplied irregularly owing to boiler priming or the presence of oil in a new boiler.

It is extremely desirable that there should be an independent steam pipe direct from the injector to the steam dome or highest part of the boiler.

Overflowing may be due to the fact that the water supply is too hot for the steam pressure. When this is the case, the trouble can easily be remedied by cooling the water.

The overflow pipe should be as short and straight as possible. Its diameter should never be less than that of the overflow branch of the injector. To convey the overflow to a distance, a short length of pipe, or a bend, should be fitted to the overflow branch, discharging at its other end into a receiving funnel on a larger pipe. The injector can then start freely and be easily adjusted and regulated.

(*d*) *Fans, Motors, and Steam Engines.*—The auxiliary machinery, which may be driven either by steam or electrically, will include, amongst other items, the forced and induced draught fans, engine driving the mechanical stoker shaft (if the stoker is not of the self-contained motor-driven type), economizer scraper engine, coal and ash conveyer or elevator engine, special blowers for vacuum ash or soot removal installations.

The most important of these are the forced and induced draught fans: especially the latter, because they are constantly subjected to a high temperature. The bearings of induced draught fans are generally water-cooled, but, owing to the high temperature, scale rapidly collects in the pipe and the water jacket round the bearings. When a little scale has formed the flow of water is retarded, offering increased facilities for more scale to form, and in due time a total stoppage occurs, unless the water service is periodically examined. It is a good plan to break the outlet pipe at some convenient place and fit a tundish. The pipe run then discharges the water into a large cone fitted to the continuation of the discharge pipe, and not only can the actual flow of water be seen, but its temperature can be felt by hand.

The impellers of induced draught fans sometimes become burnt, especially if the admission of air to the boiler is badly regulated. When the impellers are damaged in this way they produce eddy currents in the fan casing, which greatly reduce efficiency.

Forced draught fans on shore are invariably found working under water-tube boilers, either independently or in conjunction with induced draught fans on the balanced system of draught. In the latter case they are electrically driven by a motor totally enclosed to protect it from coal dust

The fan itself deals with air at atmospheric temperature, and is therefore much smaller than an induced draught fan for the same duty. Forced draught fans seldom give trouble, but the impeller should be occasionally cleaned with paraffin oil. After cleaning it should be wiped perfectly dry to prevent any accident due to the ignition of air laden with paraffin vapour. This danger is not guarded against if the impeller is dried by rotating the fan and relying on centrifugal force. If a fan impeller becomes thickly coated with oil, grease, or moisture which attracts the dust with which the air is laden, the " skin friction " is increased, and although the extra energy required to discharge the air from a rough surface is not very large, the loss is continuous, since the fans are always running. In the course of a year the cost of wasteful operation of the fans may amount to a considerable sum.

It seems to be often forgotten, when induced draught fans are installed, that the apparatus will from time to time require overhauling. In far too many cases the fan is practically inaccessible, except to a professional acrobat.

The motors should require no further attention than fitting new brushes and occasionally wiping the commutator with a clean *linen* cloth moistened with a trace of vaseline. Cotton material is dangerous, and cotton waste must on no account be used, as it may be torn out of the mechanic's hand and as it may contain metal scrap. The vaseline must be used very sparingly, and not a spoonful at a time. Dynamo-makers have as strong an objection to special compounds for lubricating commutators as boiler experts have to boiler fluids. Only in the rarest cases are these of any service, and very frequently their effects are positively injurious.

When new brushes are inserted, the engineer-chemist must see that their surface fits exactly to the surface of the commutator. Badly ground brushes are apt to damage the commutator very seriously, and carelessness in grinding must not be tolerated. A good contact at the sliding surface is essential, and to ensure this the engineer-chemist will do well, if conditions of operation permit, to run a machine with new brushes for several hours without load.

To grind brushes to shape, a piece of glass-paper should be bent, rough side uppermost, around the commutator. The brushes can then be given the same curvature as the commutator surface by moving the glass-paper backwards and forwards under the brushes until they bed properly.

Owing to the variable hardness of mica it sometimes happens that a piece of this insulating material used in a commutator is harder than the copper. After a few weeks' working the copper will be worn away to a greater extent than the mica, and a mica projection of $\frac{1}{100}$ inch will cause the brushes to "chatter," and so give rise to sparking. The application of glass-paper will make things worse, as the hard mica will not be affected, and the copper will be further rubbed away. It is, however, possible to undercut the mica slightly with the aid of a broken hacksaw blade carefully guided along its surface by a straight edge.

What has been said concerning piston rings and gland packing applies to the steam engines driving the auxiliary machinery.

Whenever possible, the exhausts from the more important engines should be collected by a special exhaust range of piping and the steam condensed. Machinery which exhausts into a condenser runs very much more smoothly, and the wear and tear are consequently less than where the exhaust is to atmosphere—quite apart from the economy obtained by using the condensed steam to feed the boilers instead of allowing it to escape into the air. The initial cost of the small air pump necessary is saved many times over, and the reliability of all auxiliary machinery is greatly enhanced.

In a large boiler plant where several feed pumps are at work, it is good practice to fit patent metallic packing in place of the ordinary soft packing. The importance of keeping the feed pumps in perfect condition hardly needs emphasizing, in view of the fact that if the supply of feed water stops, the boilers have to be shut down. It is absolutely imperative that the feed pumps shall be in perfect condition, and capable of meeting an emergency demand for additional water-supply under increased pressure. Figs 225 and 226 illustrate Messrs United States Metallic Packing Company's Atmospheric Duplex Packing, which is often fitted to feed pumps exhausting into a condenser.

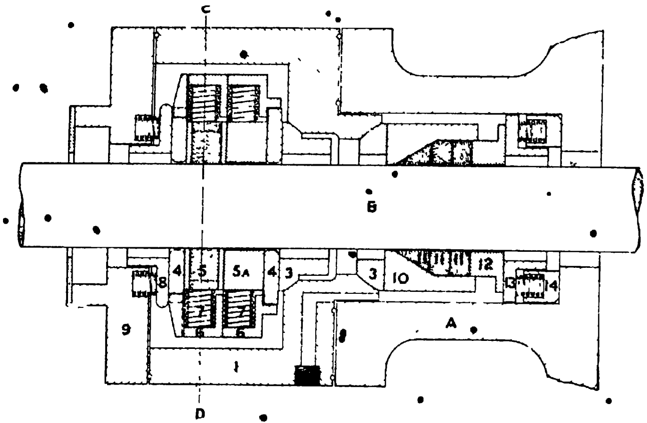

FIG 225 — ATMOSPHERIC DUPLEX PACKING, LONGITUDINAL SECTION

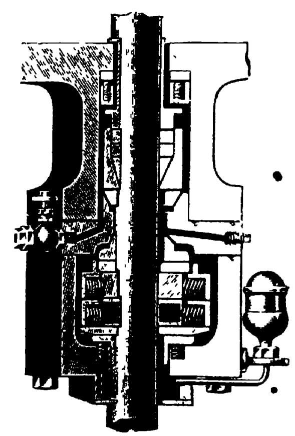

FIG 226 — ATMOSPHERIC DUPLEX PACKING, PERSPECTIVE VIEW

A very important item in connection with all machinery but especially in the case of steam-driven reciprocating engines, is the method of lubrication. Most engines are supplied with oil far in excess of their requirements, and as there is every likelihood of this oil finding its way into the boilers the engineer-chemist must take up the matter of lubrication with the mechanics. Some engines simply "swim" in oil, a large proportion of which is splashed on to the piston rod and is taken into the cylinder If the engine exhausts to atmosphere this does not matter very much, although, of course, the piston rings will become covered with a sticky black substance, and will jam in the piston, forming one solid body. But if the engine exhausts into a condenser, the condensate must be de-oiled in a special apparatus. Otherwise the emulsified oil will enter the boilers.

In large power stations where the auxiliary machinery exhausts into the main or auxiliary condensers and the condensate is pumped into water-tube boilers, proper lubrication, which will reduce the oil in the steam to a minimum before de-oiling is undertaken, assumes primary importance.

The worst trouble with oil in the exhaust steam arises from the fact that the average mechanic uses a great deal more oil than is at all necessary, sometimes several times too much. This habit has been encouraged by the circumstance that a large proportion of the oil never reaches the part it is intended to lubricate, because the oil gutters are badly designed or oil pockets are cast in the bearings themselves as a substitute for gutters. In many cases two parallel oil grooves are cut into the bearing surface, and the fact that they are there satisfies the conscience of the designer. In such bearings the oil fills these grooves, and remains there imprisoned. The bearing runs hot, and the oil is apt to cake into a solid mass which fills the grooves, so that for all practical purposes the bearing no longer has any oil grooves at all. It is essential that oil gutters should be cut flat, and the edges scraped away so that the lubricant can find its way under the journal. There is no use in cutting a deep gutter and leaving the edges sharp, because these scrape all the oil off the shaft as it revolves. Fig. 227 illustrates this point.

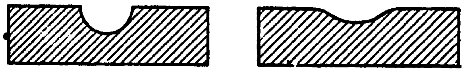

FIG. 227.—OIL GUTTERS.

The oil pipe must lead into the top half of the bearing, and must be off the centre line in the opposite direction to that in which the shaft revolves, so that a film of oil may cover the shaft before it reaches the highest point, and therefore have a chance to spread over the whole surface before the shaft reaches the lower half of the bearing surface. Fig. 228 shows the inside of the top half of a bearing with the oil gutters cut so that a maximum lubricating effect is obtained by using the minimum amount of oil.

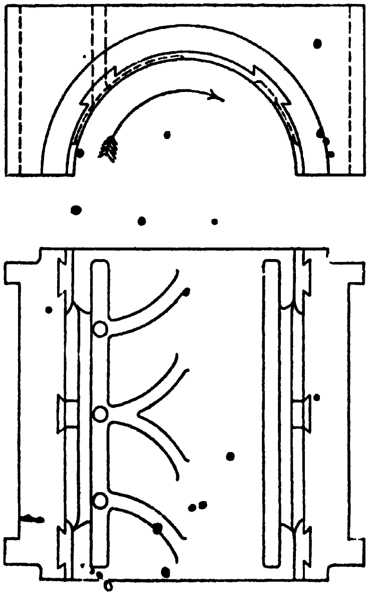

FIG. 228.—ELEVATION AND INSIDE VIEW OF TOP HALF OF A BEARING, SHOWING OIL GUTTERS.

A large bearing surface which is not properly lubricated is of much less use, and will give more trouble than a smaller bearing surface over which there is efficient lubrication. Fig. 229 shows the oil consumption of reciprocating engines on board ship, and is inserted to prove how little oil is really required if this can find its way to the spot where it is needed.

Reciprocating and rotary machinery is often out of line. Steam pumps frequently give trouble from this cause alone, and when this is so, no matter how often new piston rings are fitted, the gland packing renewed and new neck bushes made, the apparatus will continue to leak. There is only one remedy, and that is to line up the pump, commencing at the top.

With steam engines such items as cracked crank end bearings, main bearings running hot, and persistent knocking after the engine has been "done up," are almost invariably due to bad alignment. If the piston rod and connecting rod are not in line, the large end of the connecting rod will not run true, and as the error is first on one side and then on the other as the crank rotates, the bearing is, of course, twice as slack as it need be.

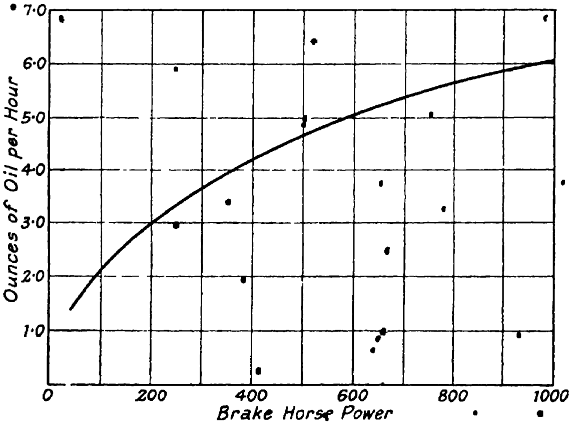

FIG. 229.—OIL CONSUMPTION.

When an engine is properly in line and runs true, it is a very simple matter to adjust the bearings when they become slack, but if an engine is out of line, it is impossible to tell what effect the tightening of a bearing may produce. If an engine is in line, any one part can be adjusted, whether it be the cross head brasses, crank end bearing, or main bearings, and the working of the other parts will be unaffected. For instance, if the main bearings become slack the covers are taken off, a thin piece of lead wire is laid over the shaft—that is, along the circumference—the top half is replaced, and the nuts are tightened up to the same extent as they were before. The nuts are again slackened, the cover is taken off, and the lead wire examined. Such a lead is shown in fig. 230.

The ends (1) are not quite as broad as the centre (2), because the clearance is greater, especially if the sides have an oil recess and the bearing surface is scraped away to allow the oil to follow the shaft. Where the lead crosses the oil gutters its shape remains unaltered, as shown at (3). The amount of wear can be ascertained by measuring with a micrometer, and a liner taken out accordingly. A bearing may be " done up " in a very short time by one fitter, and the result will be satisfactory, because the result is not dependent on haphazard guesswork, but on actual measurements which are known every time.

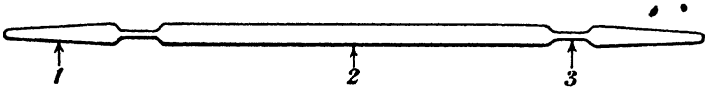

FIG. 230.—A " LEAD " SHOWING CLEARANCE BETWEEN SHAFT AND TOP HALF OF BEARING.

Small high-speed engines are often designed with a system of forced lubrication, and the makers give more attention to the design of the oil gutters, because the efficiency of the whole system depends on the satisfactory working of these gutters. Such engines are fitted with an oil well, containing a strainer which must be frequently taken out and cleaned. The oil level must also be examined, to make sure that the trough is not full of condensed steam supporting a thin layer of oil. If inspection is confined to looking through the sight glass, the condition referred to may give the impression that the sump is full of oil.

(*e*) *Dampers and Inspection Doors.*—All dampers should be easy to work, and especially those in the side flues of Lancashire boilers, because these, if the boiler is operated in the correct manner, are regulated according to the draught required. Dampers often warp and lose their shape, in which case they no longer fit into the frame, but constantly stick. If dampers are arranged for regulation from the boiler front—and this is rather the exception than the rule—either warping or neglect of the gear may be responsible for their failure to respond when the balance weight is lifted. The proper course is to remedy the defects, but too often the gear, instead of being put in order, is unreasonably reported as unsatisfactory. It is essential to the economical working of boiler plants with natural or induced draught that the dampers should be easy to work.

Dampers which warp are generally made of cast-iron which is cast too thin. There is no proper remedy, but a hole 1 inch in diameter drilled in the centre of the damper will very often retard warping. The hole also serves the useful purpose of a safety device by preventing dangerous accumulations of gases in the side flues. When the products of combustion contain a large percentage of carbon monoxide, as they may do when fires have been banked, the risk of an explosion is considerable, if this dangerous gas is able to collect in any pockets.

Dampers are frequently a bad fit in their frames, and the brickwork holding the frame may also be very loose, so that a large quantity of air rushes into the side flues past the damper and damper frame. Several patent dampers have been placed on the market, and in one of these a sheet-iron casing is built over the damper frame in the brickwork, and the only opening in the casing is a small hole in the top, of just sufficient size to give passage to the thin steel wire by which the damper is operated.

All boilers, economizer chambers, and main flues are fitted with inspection and cleaning doors. Inspection doors, like dampers, become warped, and allow air to leak into the flues between door and frame. It is advisable to install a heavy pattern door provided with at least three stout wrought-iron handles, one at the side and one each at the top and bottom. Such a door should close on a wide asbestos tape joint Cleaning doors, or sooting doors, are small cast-iron doors which, if of sound construction and made with a "half-turn closing action," should be air-tight, but these doors are frequently very light in design, and fit loosely into the wall.

It is very important that the engineer-chemist should inspect all these doors, and, if necessary, order the surrounding brickwork to be pulled down and the frame to be reset, inserting an asbestos rope round the frame so that the casting has a certain amount of freedom to expand If this is not done, the fireclay between the frame and the wall will soon become detached once more, and the door will leak air as badly as before

Air leaks are the bane of the engineer-chemist's life, and he must always be on the lookout for fresh leakages, because, whilst he is searching for and repairing one lot, another lot will be forming

CHAPTER XX

AUXILIARY PLANT BRICKWORK

(*a*) *Flues.*—The efficient working of Lancashire, Cornish, and water-tube or other boilers surrounded by brickwork, from which the products of combustion escape through brickwork flues, depends to a large extent on their design, layout, and efficient protection against air leakages at the most vulnerable points. The remarks made in the last chapter on the subject of air leaks apply with equal force to the care of flues. Here, therefore, it is necessary only to refer to their design and layout.

A brief indication of how complicated the layout of the flues may be in the case of a boiler plant attached to an old-established factory or works has been given in Chapter I. It is impossible to lay down hard and fast rules of universal application to the arrangement of flues, because this will depend on the position of the boiler plant with reference to the remainder of the factory buildings, the amount of space available, and the size and type of the power plant. Fig. 231 shows a scheme for a power plant, consisting of two Lancashire boilers, superheaters, economizers, and induced draught fan. The dampers are arranged in such a manner that the gases, after leaving the boilers, pass through the economizers and then to the inlet side of the induced draught fan, and this is, of course, the usual method of working. If the economizers are being cleaned, the gases are sent through the by-pass flue, but the induced draught fan may still be used. When the fan is not working, the gases may travel direct to the chimney, either passing through the economizer or through the by-pass flue. Sharp bends should be avoided, and the brickwork should be so designed that the gases may flow in an unbroken stream, and not collect in pockets, or form eddy currents.

When the flues of a boiler plant are to be cleaned, the engineer-chemist should first make a careful inspection of their interior, and note how the heaps of soot have collected in the different corners and passages. In this way he will get a good indication how the gases travel when the plant is at work. If he suspects that bad eddy currents are created in a certain part, he may either install steel deflector plates —as, for instance, where the side flues from Lancashire boilers enter the main flues —or he may dump some concrete made of broken clinker and cement into the offending corners, sweeping the surface away so that it meets the walls in a comfortable curve.

Although the net area of a flue as calculated mathematically may actually be reduced by making alterations as just suggested, the doing away with all sharp corners and other irregularities which may tend to produce eddy currents will have a beneficial effect.

If the layout of the flues is very bad, so that the gases follow an extremely tortuous course or have to rise vertically or dip under some obstruction, the engineer-chemist should obtain permission to reorganize the flues. This task can generally be undertaken without disturbing the working of the plant. For instance, one wall of the old flue may be retained, and, because the flues are generally too small, the new wall can be built on the outside of the old flue. A temporary stopping can be made between the old and the new outside wall wherever required, and a portion of the old wall removed every week-end, or whenever a suitable opportunity presents itself.

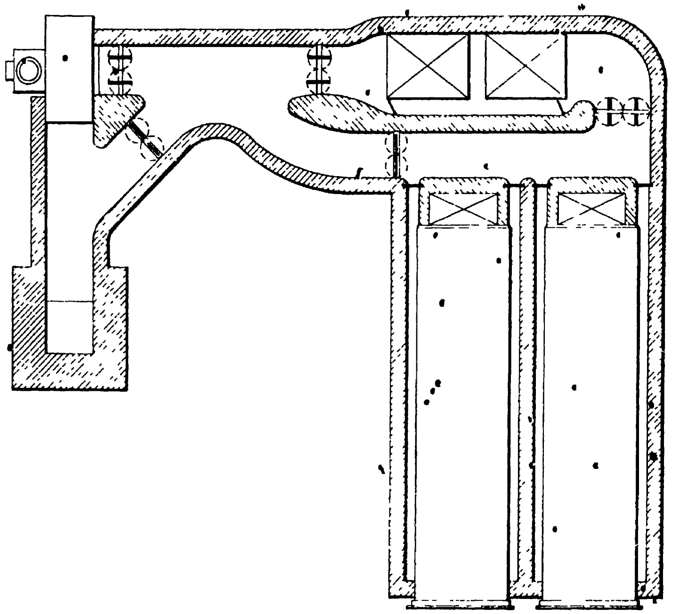

Fig. 231.—A Lancashire Boiler Plant.

Although it is not essential to line a flue with firebricks, it is most advisable to do so, because the ordinary red brick will be better protected from the hot gases and the probability of air leaks occurring will be greatly reduced. The cost of firebricks should not be grudged, because if the flues are being reorganized to improve the efficiency of the plant, it is worth while to make "a good job" in all respects. Reference was made in Chapter XVII to the use of asbestos tape and rope for interlining the brickwork, with the view of minimizing the chances of air leakage. This may be adopted with advantage when the outside wall of a flue is curved, especially, if the radius has to be kept within small limits, due to lack of space.

Whenever the flues are curved, special bricks must be used. It is not good practice to cut ordinary bricks and to fill the irregular spaces with cement or fireclay. If the cement or fireclay does not bond with the bricks, it will soon contract when heated, and fail to fulfil the purpose for which it was intended. When laying bricks, the secret of making a tight joint is the same as in every other case—namely, the binding material or joint must be as thin as possible, and no other service than that of making a joint should be required of the binding material.

When starting up a new boiler plant, the flues should be warmed up very gently for at least three or four days in order to give the brickwork a chance to evaporate all moisture, and to become accustomed to the increase in temperature. A wood fire is better than a coal fire for this purpose.

When a new boiler is installed in an old plant, and the main flue enters the existing chimney by a new opening which is opposite to that of the old flue serving the existing boilers, special precautions are necessary. Especially in plants worked with natural draught the gases from the old boilers may sweep into the base of the chimney with such force that they block the free admittance of the gases from the new boiler, and therefore deprive it of most of the draught. Under such conditions the new boiler will not burn the amount of fuel it should, because the supply of air will be insufficient, due to the poor draught. Inevitably the maximum evaporation of which the boiler is capable will not be obtained. The installing of proper deflectors in the base of the chimney will probably ameliorate matters.

(*b*) *Superheater Chamber.*—The superheater, working in conjunction with an ordinary Lancashire or similar type boiler, is located in the brickwork chamber at the end of the boiler. This brickwork chamber is always installed, whether a superheater is at work or not, because it provides the seal between the end of the boiler and the side flues, deflecting the products of combustion downwards and forcing them to return to the front of the boiler instead of escaping into the main flue. It is therefore very important that this brickwork chamber should be a tight fit against the end of the boiler. In the usual form of construction the bricks are built close up to the boiler when it is cold; the long shell of the boiler expands when at work, and forces the brickwork away, in which position it remains when the boiler contracts. The result is severe leakage of the gases straight from the boiler flues into the main flue, and all the heat that could be delivered to the boiler if the gases had to return under the boiler and pass through the side flues is lost to the boiler. Where a superheater is installed, such leakage is of great importance, because the gases, instead of passing through the superheater tubes, will simply pass in front of it, and away through the cracks in the brickwork into the side flues. Asbestos rope bedded in the ordinary brickwork will improve matters, but a better arrangement is that which was shown in fig. 208 when describing Messrs. Milner Hurd's patent system of setting Lancashire boilers.

The superheaters installed inside water-tube boilers are not in a special brickwork chamber, but are in what might be termed a separate compartment. The baffle tiles or bricks are arranged in such a manner that the gases in their passage through the boiler sweep round the superheater tubes. It is therefore essential to efficiency that the baffling arrangements should be in proper condition to prevent the gases short-circuiting in the boiler and missing the superheater.

Locomotive and Scotch marine boilers are fitted with a special type of superheater, in which one tube shaped like a very flat ⊃ is situated in each smoke tube.[1] [2]

With boilers which have a special superheater chamber, this must be built of good fireclay bricks set with fireclay used very sparingly The best procedure is to dip the bricks in a thin wash of fireclay and rub the brick down to a joint. Cement should not be used under any circumstances It is often used because the adhesive properties of fireclay are very poor, but ordinary mortar may be substituted when the temperature does not exceed 500° F. Silica bricks should not be used They are quite unnecessary for the comparatively low temperatures met with in the flues of Lancashire boilers, and they are expensive A yet more serious objection is that they will expand and cause the walls to bulge inwards if they cannot expand vertically.

(c) *Economizer Chamber* - The economizer chamber is built of ordinary red brick, with a firebrick lining if a specially good job is required. The chamber should be of ample size to allow a man to walk all round the economizer for cleaning and inspection purposes[3] It should not be below the ground-level, and should preferably be raised sufficiently to bring the soot chamber level with the ground, where it can conveniently be cleaned. Where the subsoil is damp, or in proximity to rivers or canals, the chamber must be raised well above the ground The construction of the chamber must in all cases be such as to provide ample facilities for cleaning and inspection, and there must be no air leaks if efficiency is desired in operation.

Economizer chambers very frequently pass air on the top, where the side walls meet the cast-iron headers, and at the bottom between the inlet branches to each segment of tubes. The top joint can most satisfactorily be made by inserting a double thickness of sheet lead between the side wall and the economizer, bending over the two ends, and hammering down flat. The bottom joint can be made air-tight by the use of asbestos interlining, but a good fitting brick not small remnants left over when bricks were cut in building the walls properly set in place with good mortar will make quite a satisfactory job, because the brickwork is not exposed to wide variations in temperature

Sometimes the engineer-chemist will find it necessary to obtain permission to make structural alterations for the purpose of securing a satisfactory layout of the economizer. This apparatus should be so located that the pull from the chimney (in the case of natural draught plants) or the inlet to the fan (in the case of plants fitted with an induced draught fan) will be right through the centre of the economizer. The entrance to the economizer should not be abrupt or of such a nature that the gases cannot follow the stream-line motion and flow naturally through the economizer. In many cases they have to force their passage past the tubes in a very agitated fashion, with the inevitable result that back currents are set up which destroy much of the draught which would otherwise exercise a beneficial effect on the fires in the boilers. The arrangement of the economizer varies to a great extent, and is chiefly dependent on the space available. Generally the products of combustion follow a straight path on their way to the chimney, in which case the economizer chamber may be said to form an elongation of the main flue. In some cases the gases divide and, passing in opposite directions through two separate economizers, meet again in the centre, and pass away to the chimney. Another arrangement is for the gases to pass through two economizers, either in parallel or in series. In the first case, the gases are divided, and after passing through the economizers situated next to one another, enter the chimney. In the latter case the gases are not divided, and all of them pass first through one economizer and then through the second. Whatever the layout of the plant, the engineer-chemist must see that the draught is not impaired, owing to air leakages or excessive resistance.

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[1] *A Manual of Marine Engineering*. A E Seaton

[2] "Effect of Superheating on Locomotive Working," *Trans. Inst. Mech. Eng.*, p. 345, 1913.

[3] *Boiler Inspection and Maintenance*, R. Clayton

(*d*) *Chimney*.- The engineer-chemist will see that large deposits of soot do not collect in the base of the chimney to hinder free entrance of the gases and their upward passage. A heap of soot may cause deflection, which will produce curling, thereby greatly increasing the resistance inside the chimney, and reducing the draught. The entrance to the chimney must be examined for cracks, especially round the main damper frame. It is essential that the main flue should not support any of the weight of the chimney brickwork. Some chimneys have several openings, and no provision is made to support the brickwork immediately above them. When a new opening is cut into an existing chimney, a heavy steel joist should be inserted, with the ends securely resting on the side walls of the remaining chimney brickwork, so that the pressure is transmitted to the foundations.

When a new chimney is built, two or more openings should be made, and the brickwork set in the shape of a self-supporting arch. The openings that are not required, but have been made with a view to possible future extensions of the power plant, are bricked up with a temporary stopping.[1] If this has been properly done, the brickwork can be removed, when the opening is to be used either for cleaning or to form the entrance of a new flue, without any fear of the chimney settling or suffering in any other respect.[2]

The exhaust steam pipes from small engines are frequently led into the base of a chimney on the fallacious theory that the draught will thereby be increased. The steam can only increase the draught, after the fashion of a locomotive blast pipe, if it is sent through a properly designed nozzle. In that case, the steam, when it expands, takes a certain amount of the surrounding air with it, because the steam moves at a high velocity and creates a partial vacuum which is filled by the inrushing air. Many complicated theoretical questions are involved, but the governing principle is that of an increase in velocity, and the exhausts from small engines have nothing like sufficient pressure to create an appreciable draught in the great height of an average industrial smoke stack. If the pipe of, say, a boiler feed pump which exhausts to the atmosphere be watched, it will be seen or felt that there is as much water as there is steam. The result of introducing such exhaust pipes into the base of chimneys, especially steel chimneys, is to cause rapid corrosion.

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[1] *Boiler Draught*, Key Pratt.

[2] *Boiler and Factory Chimneys*, R. Wilson.

Chimney foundations need watching in exactly the same way as boiler foundations (see Chapter XVII). In the case of old plants the main flue often enters a near-by hill, and connects with an opening under the chimney. More often than not, water collects in the main flue, and any advantage that may accrue from the lofty position of the chimney is soon negatived.

Modern practice is to fit a short steel chimney, the top of which is as many feet above the ground as the local authorities require, and to rely on a forced or induced draught fan to supply the air required for combustion, or to take away the products of combustion, as the case may be.

The outside of steel chimneys should be thoroughly cleaned with steel wire brushes every two years, and the plates painted with a coat of good oxide of iron and boiled oil, followed by a coat of superior black paint Such chimneys may, with advantage, be lined internally with firebrick to a distance of one-fifth to one-quarter of their height

The engineer-chemist may be in charge of a power plant which has a chimney of pagoda-like appearance Its quaint shape may be due to the incorporation of special grit arresting construction, to the chimney being used to support a water reservoir, or to the inclusion of a lookout gallery.

When discussing the merits of forced or induced draught as compared with natural draught, it is constantly said that, in the case of natural draught, once the chimney is "up," it is "up," and there the matter ends. Quite apart from the disadvantages of natural draught, its limitations, and the impossibility of increasing it temporarily in emergency, a brick chimney is very expensive compared with a short self-supporting steel chimney and fan, of which the running and maintenance costs need not be high In the case of a brick chimney, unless the owners allow a sufficient margin to cover all probable developments of their business during the life of the chimney, the latter will almost certainly soon be too small to serve the plant efficiently under natural draught conditions For obvious reasons of expense, it is unlikely that they will be prepared, when this condition arises, to scrap the existing chimney, and erect a larger one.

CHAPTER XXI

WORKSHOP ORGANIZATION

(*a*) *Training of Staff*.—The size of the boiler department's repair shop will vary with the size of the plant. It is, of course, very desirable that the boiler department should have its own repair shop and staff of skilled men, but where the plant is very small a general repair shop is usually shared by all the departments. In such a case separate accounts must be kept of the work done for each department, so that accurate costing sheets may be drawn up.

Whether the department has its own workshop or shares the general repair shop, the engineer-chemist must have the right to engage the men who are to work under him. When engaging fitters, machine men, boilermakers, pipe coverers, or other men, it is wise not to rely too much on what the men have done elsewhere, but to engage them on a week's trial, informing them at the time of engagement that this is the case. A thorough and conscientious worker, who may be a little slow, but in whom absolute confidence may be placed, is preferable in the case of boiler work to the "ultra-smart" man who knows what is required before he has been told, and about whose work it certainly cannot be said that when it is done it is well done.

The anxieties of the engineer-chemist will be considerably reduced if he knows that he can rely on the mechanic in charge of the repair shop in the event of an emergency. He will therefore put his trust in one of the older employees who has been brought up on the plant. He will discuss with this mechanic the various changes he has in mind, always remembering that although he himself has enjoyed the advantages of a more expensive training, it is the old employee who, from experience, has the requirements of the manufacturing department at his finger tips. By combining their respective qualifications it will become possible to build up a perfect organization. It is likewise a good plan to encourage local labour by taking an interest in the training and welfare of the rising generation, so that, when a system has once been built up, it may become an integral part of the whole organization, and live from generation to generation, irrespective of who may be at the head.

It has already been pointed out in various connections that the engineer-chemist is responsible for the safety of all the plant under his care, but he is also responsible for the safety of his staff, and this responsibility often causes as much worry as the plant itself. The machinery and everything connected with it can be made quite safe by regular inspection, fitting guards wherever necessary, installing reliable safety devices, and keeping the plant in a proper state of repair, but the human element still remains the uncertain factor. The precautions necessary vary with every plant, because, as stated in Chapter I, no two boiler plants are exactly alike. Mention has been made of several possible sources of danger, and the means of avoiding accidents when opening and cleaning boilers, but some men constantly take quite unnecessary risks, either through carelessness or lack of proper instruction.

When heavy lifting with the aid of mechanical appliances has to be done, for example, the workmen often expose themselves to danger by reason of their poor knowledge of the art of slinging. In lifting long heavy pipes and bars from a vertical position, special care is required, especially if the pipes or bars are covered with a coat of grease. Fig. 232 shows two simple knots.

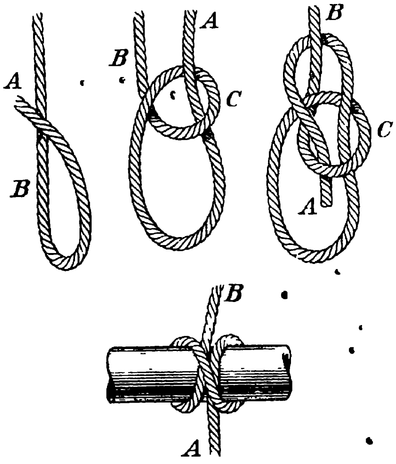

Fig. 232.—Bowline and Clove Hitch

The upper part of the illustration shows how to make a bowline, which is a most useful knot to form a loop that will not slip. Lay the end (A) of the rope over the standing part (B). Form with (B) a bight (C) over (A). Take (A) round behind (B) and down through the bight (C). This is the correct method of making a loop for hooking on to a chain lift or pulley block when slinging a heavy object, which cannot be taken with an ordinary sling, but which has to be slung by using a length of manilla rope.

The lower part of the illustration shows a clove-hitch, which is a very useful knot for fastening spars together, when rigging up a tripod mast with ordinary wooden poles. Pass the end (A) round a spar and cross it over (B). Pass it round the spar again and put the end (A) through the second bight.

When it is required to lift an economizer pipe or similar long object which has no projecting parts, the knot shown in fig. 233 should be used.

This knot is simply a double clove-hitch applied right-hand and left-hand to the pipe, and locked with a reef knot. This sling enables a perfectly vertical pull to be exerted, and even though there be only $\frac{1}{100}$ inch clearance round the pipe, a clear lift is obtained, and the object can be raised without constantly fouling the sides.

It is surprising how easily a mistake can be made in tying an ordinary reef knot with a stout rope. When tying a piece of string the action is more or less a mechanical one, but when a stout hemp rope has to be manipulated—and for reasons of weight the ends must be inserted separately before the knot can be pulled tight—

trouble can often be avoided by remembering the words "right over left, then left over right."

If a rope is too long it must, of course, not be cut. To make an ordinary knot is a very clumsy and unsatisfactory method of shortening, because when the weight is lifted the knot tightens and stretches. To shorten a rope, always make a sheepshank by gathering up as much of the rope as is not required. Then form a half-hitch with each end of the rope by passing the slack end round each end of the bight and passing through the part gathered up.

Whilst dealing with the art of binding ropes, a few words can with advantage be inserted on the making of packing. Packing for steam and water glands is made by a large number of manufacturers, and in all sizes, so that the ordinary apprentice has but a hazy notion how it is made. When he becomes a full-fledged mechanic, and is called upon to make a short length of packing, perhaps whilst working over a week-end when the factory store happens to have run out of the size he requires and it is impossible to make a purchase, he is at a loss what to do.

Great emphasis has also been placed on the importance of stopping all air leaks; and because these can very often only be sucesssfully stopped by filling with asbestos—or, in some cases, ordinary—rope a short description is given how to make packing by plaiting a square sennit. Figs. 234 and 235 illustrate clearly how this is done.

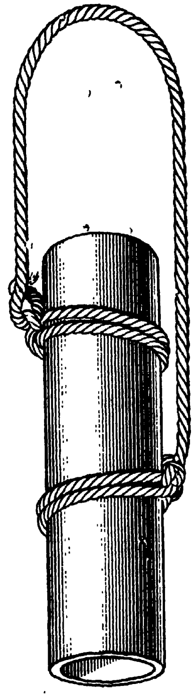

FIG. 233.—SPECIAL METHOD OF SLINGING PIPES.

Eight strands of rope or asbestos cord are taken, their thickness depending on the size of sennit required, and the ends are gripped in a vice. Four strands are taken in the left hand and four in the right hand. The outside strand in the right hand (No. 8) is passed underneath and then over the inner two in the left hand, so that at the end of the performance the strand is still held in the right hand, but instead of being on the outside it is on the inside. The operation is repeated with the strands in the left hand; the outside strand is passed underneath, and then over the two inside strands held in the right hand and taken back to the left hand. The process is simply one of working alternate sides, and taking the outside strand of one side under and then over the two inside strands of the opposite side. The strands never change sides—that is, Nos. 1, 2, 3, 4 are always held in the left hand, and 5, 6, 7, 8 in the right hand.

(*b*) *Method of Working.*—The men in the repair shop will work according to a definite routine. Their work will be divided into internal and external work.

Internal work is that done by the machine men, blacksmiths, and valve fitters, while outside work is that done by the boilermakers, pipe coverers, and outside fitters. The outside fitters will at times work in the repair shop, as already explained when dealing with the overhauling of boiler mountings, furnace gear, etc., but the inside staff should have no occasion to roam round the plant on the pretext of trying a machined valve in its place or for any other reason If they want to have a smoke, it is far better for the engineer-chemist to turn a blind eye, and allow them to do so in the workshop than to lose sight of them for an indefinite period. A hard-working, conscientious workman will appreciate these little concessions, and the type of man who, when permitted to smoke, will make smoking an excuse for stopping work is not worth employing.

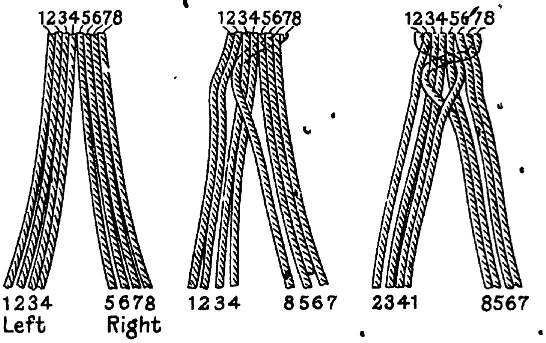

FIG. 234.—PLAITING A SQUARE SENNIT.

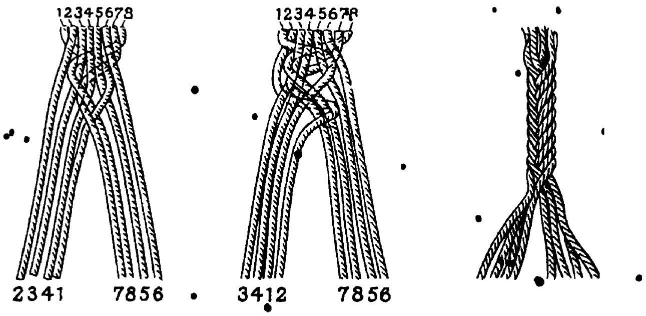

FIG. 235.—PLAITING A SQUARE SENNIT.

In every repair shop a certain amount of repetition work has to be done in connection with the maintenance of the power plant, and it is here that the engineer-chemist can show his capabilities as a mass-production organizer. Boiler stop-valves, feed-check valves, blow-down cocks, safety-valves, and other fittings require attention whenever a boiler is opened for cleaning or inspection. It should not be necessary to wait for any details as regards size or construction of parts that often require renewal. Spare valves can be kept in stock, and also any other patent internal parts that may give trouble. The machine men should know what is required in the case of such repetition work, so that they need not wait for orders, but get on with the job as soon as it comes into the shop. There is, of course, also a considerable amount of work which never repeats itself, or, at least, only at long intervals.

Certain jobs require special tools or apparatus to be made. Such gear should be labelled and hung up in the store so that it can easily be found when again required. For instance, large valves generally wear away more quickly than the seats, and the metal of such a valve is frequently softer than that of the seat. In such a case it is not much use grinding in the valve, because the metal will all be ground away before the seat shows any sign of improvement. A steel plate should, therefore, be turned in a lathe, so that it has the same diameter and bearing surface as the valve. A hole should be drilled in the centre of the steel plate and a stout handle with a T-shaped top should be securely fastened by means of two locking nuts. The valve seat can then be ground in until all the flaws have disappeared, and the valve itself need be used only to obtain the final finish.

To grind in a valve and make a really steam-tight joint calls for more skill than is generally admitted. If a valve is badly corroded, it must first be skimmed up in the lathe. If the seat is in a specially bad condition emery powder may be used, but this is dangerous stuff to work with, because, unless special care is exercised, the only result obtained from its use will be a series of grooves cut deep into the metal, which will make the valve leak more than before. When a valve is to be ground in, the very finest carborundum powder, moistened with lamp or colza oil, may be used. As soon as the face shows signs of a good surface, no more carborundum must be applied, but very finely powdered bath brick. When a good surface has been obtained, no more bath brick is required, but grinding in should continue, using lamp oil to keep the surface moist. In this manner all the powder is ground away, and the valve becomes highly polished. The valve seat and valve must be thoroughly cleaned to remove every trace of powder. Otherwise the water or steam, as the case may be, will remove the grit, and this will probably find its way under the seat, causing the valve to leak.

Small valves are particularly difficult to deal with, because the seat is frequently low down in the body of the casting. The valve is, of course, fixed to an eyebolt which is screwed into a tapped plate inserted under the horseshoe, but the likelihood of giving the valve a swivel motion instead of a truly circular one nevertheless remains.

It is a good plan to make a guide, as shown in fig. 236.

The rose-cutter for cleaning the seat, or the eyebolt for holding the valve, is inserted into the guide, which is then screwed on to the valve in place of the ordinary cover. A truly circular motion is obtained when grinding in the valve, because the eyebolt remains vertical. The guide is recessed at the bottom, so that the valve may be lifted after each turn. This is absolutely essential when grinding in any valve, as otherwise the grinding powder remains in the same place all the time. Grinding in valves with a brace may be satisfactory in some trades, but it is worthless if a good steam or water-tight job is required. Elbow-grease, and a lot of it, is the only remedy for a leaky valve, unless the valve and seat are put into a lathe. A patent reseater is a very useful piece of apparatus to have in a fitting shop, as it obviates removing the valve seat.

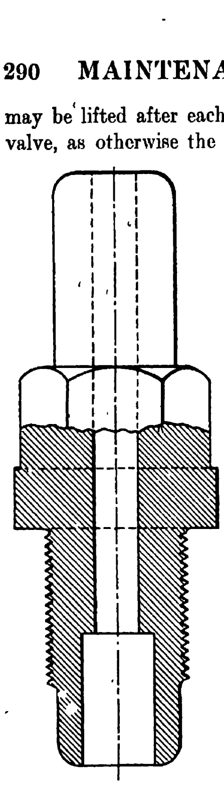

FIG. 236.—GUIDE FOR GRINDING IN SMALL VALVES.

The engineer-chemist must see that a high standard of workmanship is always maintained by the men, and he should always inspect engines, pumps, valves, etc., before they are closed up. The indicator card shown in Chapter XIV. (fig 151) was taken from a small reciprocating engine driving a centrifugal pump, and the reason for its queer shape is that the engine was fitted with a piston valve taking steam on the inside, and after repair the valve was put back the wrong way up. The queer shape of the card will be readily understood by looking at fig. 237, which shows the effect of placing (B) where (A) should be. The engine ran satisfactorily, but the steam consumption was far too great. Had there been proper inspection when the engine was assembled ready for closing up, the mistake could not have happened.

In another connection mention was made of the fact that engines use more oil than is necessary, because the oil gutters are incorrectly cut, but much is also wasted by the carelessness of mechanics. In winter the viscosity of oil, and especially of cylinder oil, is very high, and the filling of an oil pot or can takes a considerable time, and because the youth measuring out the oil thinks the proceeding is too slow, he does not turn the tap off until the can is full. What is left in the pipe or cock consequently overflows, and is wasted. To obviate this waste the engineer-chemist should have an oil warmer installed in the store or workshop. Such an oil warmer can easily be made from scrap materials, and it is constructed like a condenser. Two pieces of steel plate are turned to be a neat fit in a steel drum or barrel, and the plates are drilled to take the circulating tubes and ferrules. If the warmer is for heavy cylinder oil, exhaust steam at atmospheric pressure is a suitable warming

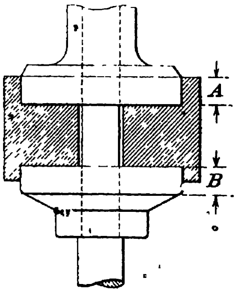

FIG. 237.—REVERSED PISTON VALVE COLLAR.

agent; but if it is for ordinary engine oil, warm water must be used, as otherwise the oil may become overheated and lose some of its lubricating properties, besides clogging the inside of the heater. A small pipe may be taken from the feed range before it enters the boiler feed pump, and the feed water, having been heated with exhaust steam before it enters the economizers, will be just the right temperature for warming the oil. As the water does not come in contact with the oil, it may be all sent back to the feed heater, so that none is wasted.

Fig. 238 shows a brass ferrule for use in steam-heated, and a wooden ferrule for use in water-heated, oil warmers. The tubes are short lengths cut from old condenser tubes. The apparatus also has the advantage that a known quantity is poured in at a time, and the oil consumption can therefore be better checked. Oil is as useful for domestic purposes as it is in the boiler house, and unless a close watch is kept on its consumption a surprisingly large quantity will disappear without any record of the use to which it has been put.

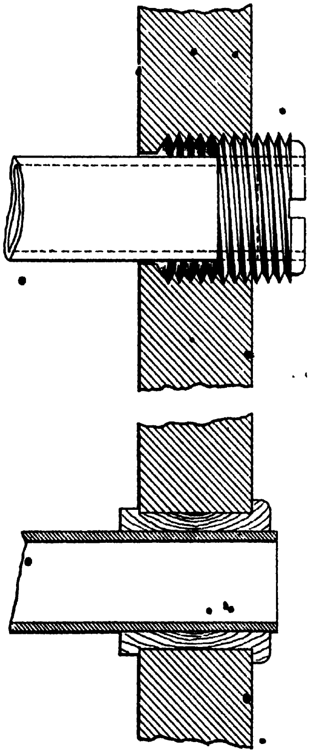

FIG. 238.—FERRULES.

There remains for consideration the vexed question of tools—especially spanners. The workshop should be fitted with a spanner rack containing a large number of spanners, and a notice should be posted near by, warning men that if they are caught damaging or neglecting to return spanners, they will be heavily fined. To see the nuts of a nicely finished brass valve indented with deep chisel marks, because the individual who last opened it did not use a spanner, is a cause for shame to everybody concerned. There is no excuse whatever for such practices.

All tackle should be kept clean and well oiled, and wire slings should be soaked in an oil bath twice a year. The oil collected from the drip trays of the larger engines will answer this purpose very well. Wire slings often get wet. The water penetrates to the inside, and the steel wire commences to rust. Nothing happens for a long time, but one day, when a heavy casting is being lifted with the sling, it breaks, and in all probability a workman is severely injured.

Hemp ropes are often used in a careless manner, and the sharp edges of objects lifted are allowed to cut away some of the strands, thus weakening the rope—which may produce the same results as a rusty wire rope. When lifting heavy objects with sharp corners, old bags must be placed between the metal and the rope, for the protection of the latter.

Waste oil may be separated from water by pouring into a settling tank made out of an old drum fitted with two cocks. One cock is placed a few inches from the bottom of the drum, and the other in the middle. When the liquids have been allowed to settle, the water and oil are run off by the two cocks. If the oil is to be used again, it must be passed through a filter, such as the Wells waste oil filter.

SECTION *XII.*—REPAIRS TO SUBSIDIARY PLANT

CHAPTER XXII

FEED WATER PLANT

(*a*) *Examination of Source.*—The source of the water should be examined daily to make sure that no impurities are taken into the feed supply range. Where the water is taken from a river or pond a grid is often fixed to the inlet weir to prevent twigs, leaves, etc., from entering the system. The grid should be cleaned daily. Tunnels or artificial inlet channels should be cleaned once a month to make sure that no algæ or fungi which might produce contamination, due to the presence of micro-organisms, are beginning to grow. Although the introduction of these into a boiler has little effect so far as formation of solid matter is concerned, the acids formed in the boiler by their decomposition may do very serious damage.

Pond or river water is often passed through ordinary filters to remove the fine solid impurities held in suspension. These filters need cleaning, the period between successive cleanings depending on the degree of impurity of the feed water. The newer types of filter are fitted with special compressed air cleaning pipes. The water-supply is cut off, compressed air is blown through the quartz and pea gravel, and the flow of water through the filter is reversed until all the filtering medium has been thoroughly cleaned. The flow of cleaning water is then stopped, and the filter is ready once more for filtering the boiler feed water.

(*b*) *Treatment Plant.*—Water softening plants are supplied with special cleaning arrangements, which generally consist of valves or cocks placed at the bottom of the settling tanks. The water softening plant is mounted on a concrete base in which special channels are made, so that the sludge when leaving these cleaning valves or cocks will be conducted to a drain connected with a main sewer. This obviates any fear of the sludge contaminating any other source of water-supply.

The insides of the tanks, and especially the mixing gear, become heavily coated with scale, and as the working of the apparatus may be impaired from this cause, the whole water softening plant should be thoroughly scaled, cleaned, and washed out once every year. It is of the greatest importance that the tanks should be properly washed out before the quartz or wool slag is replaced, as, if this is not done, small particles of scale will settle on the filtering medium.

Slag wool is very cheap, and therefore can be renewed as often as necessary. In some cases the top layers become quite green, which means that organic growth is taking place. As this is undesirable, the filtering medium should be renewed before this occurs.

Oil filters need periodical cleaning, the duration of time between cleaning depending on the construction of the filter and the quantity of oily water passed through it.

In Chapter X. it was stated that the principal impurities in feed water used by land boilers, and those which form the bulk of the scale deposited, are the salts of lime and magnesia, with special reference to calcium carbonate, calcium sulphate, magnesium sulphate and magnesium chloride. Most of the salts are soluble in water at ordinary temperature, but when some of the water is evaporated, and the remainder becomes too saturated, the salts deposit as scale-forming matter. It is therefore of great importance that all the salts should be removed by the water softening plant, which must be kept in good condition for that purpose.

The hardness of water is sometimes expressed in degrees and sometimes in grains. A degree is equal to one part by weight of the offending salt in 100,000 parts of water, while a grain is equal to $\frac{100,000}{70,000}$ or $1\frac{3}{7}$ degrees of hardness, because a gallon of distilled water weighs 10 pounds and contains 70,000 grains. By using reagents made up in the form of standard solutions the exact hardness of a water may be ascertained.

It has been said that the boiler water must be tested. And this will ordinarily be done by taking samples of the water before and after it has been softened. These two samples will be analyzed in the laboratory, and the results obtained from the hard water sample will give an indication as to how much lime and soda ash must be added to soften the water. The second sample should show, when tested, that the treatment has been correct. The tests will be made in the laboratory, and the results sent into the records office for examination by the engineer-chemist.

Many works have their own laboratory, and although the duties of the staff are in connection with the manufacturing departments, there is no reason why they should not include the testing of water and fuel until an organization has been set up for the boiler department on the lines explained in a previous chapter. Eventually, of course, the boiler department will engage and pay for the services of a special chemist, who may or may not work in the general laboratory. There are, however, many other firms which do not possess a laboratory, and until they tackle in real earnest the problem of the economical generation of steam, it will be necessary for them to work in a very modest way, and to test their feed water in a manner which does not involve the handling of expensive apparatus.

As already explained, the ordinary plant mechanic has no time to go deeply into the chemical study of this all-important subject, even if he has the inclination to acquire additional knowledge in this direction. A few simple hints are therefore given for his guidance. They will suffice to place on record whether the boiler water contains ingredients harmful to the boiler or not.

To test the feed water for hardness, the following apparatus is required: A glass bottle fitted with a glass stopper, a measuring cylinder graduated in cubic centimetres, and a bottle of potash soap solution, Wanklyn's strength.

Measure 70 c.c. of feed water by filling the graduated cylinder to the 70 mark, and pour the water into the stoppered bottle, which, for convenience, should have a wide neck. Measure out 2 c.c. of soap solution, and pour them also into the bottle. Replace the stopper and shake vigorously. If a good lather is obtained, and lasts five minutes, the water contains 1 grain of carbonate of lime per gallon, equal to 1 degree of hardness. If the lather disappears very soon, add another cubic centimetre of soap solution until a permanent lather is obtained. The number of cubic centimetres of soap solution, *minus* 1, is equal to the number of grains of carbonate of lime per gallon. Thus, water containing 16 grains of carbonate of lime per gallon requires 17 c.c. of soap solution to produce a permanent lather. By thus testing the water before it enters the boiler, the mechanic can ascertain how much scale-forming matter is being introduced into the boiler.

The practical engineer is, however, equally interested in the water inside the boiler, because the actual decomposition of impurities introduced into a boiler is not known, but is only a subject for guesswork. Every precaution may be taken in the purification of the feed water, and yet unexpected results may be obtained. The water in a boiler may theoretically be either acid, alkaline, or neutral. It is neutral only when it is pure distilled water, and such ideal conditions are never found in practice, although in some cases the water is so very slightly alkaline that the condensing apparatus and "make up" feed water treatment plant work at very high efficiency. Boiler water may therefore be regarded, for practical purposes, as either acid or alkaline. It should never be acid, because this produces corrosion. Excessive alkalinity is also not good, but it is less harmful than excessive acidity—which is, in fact, fatal. Excessive alkalinity is generally due to an excess of caustic soda, which rapidly attacks the brass boiler mountings.

To test the boiler water, draw off a sample through the salinometer cock, or through the drain cock on the water gauge, taking care to close the steam connection first. Whichever method is adopted, allow a good quantity of water to blow through first, to ensure that a true sample is obtained. Test this sample with litmus paper. Litmus paper can be bought from any chemist in the form of little books, red and blue. Red litmus turns blue when dipped into an alkaline solution, and blue litmus turns red when soaked in an acid solution. If the boiler water is in a satisfactory condition, it should cause red litmus paper to turn slowly blue, showing that it is slightly alkaline.

A more delicate test may be carried out on similar lines by using a book of phenolphthaleïn papers. These are white in colour, and when placed in an acid water do not change, but when introduced into an alkaline water immediately turn the water a vivid purple, the intensity of the purple being an indication of the alkalinity of the water. This may, therefore, be looked upon as a confirmative test of the presence of an alkali. If a blue litmus paper has turned red, showing acidity, the extent of this acidity should be determined. An indication, which is quite accurate for a confirmative test, may be obtained by using a solution of methyl orange.

A burette, as shown in fig. 239, is filled with methyl orange. The water to be tested is poured into a porcelain basin, and the methyl orange added drop by drop. The water must be well stirred after each drop is added. If the water is alkaline the yellow colour will remain, but if the water is acid each drop of methyl orange will turn the water pink. Add the reagent until a pink discoloration takes place, and an approximate idea of the acidity of the water will then be obtained. The indicator is prepared by dissolving 1 grain of methyl orange in a small quantity of pure methylated spirit (*i.e.*, free of water) diluted with its own volume of distilled water.

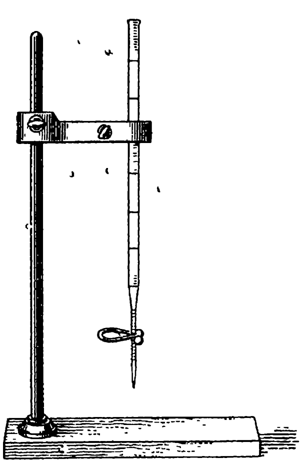

FIG. 239 – BURETTE

When boilers are supplied from wells the water should be tested for chlorides, which, if present, will corrode the boilers, owing to the harmful effect of hydrochloric acid which is generally formed by their decomposition. Silver nitrate is used for such testing. One drop will turn ordinary drinking water turbid; and if any sodium chloride is present the boiler water will become milky in appearance. The chemical examination will show the exact amount of reagents that require to be added to soften the water, and it is important that these should not be used in excess. Scientific control of the water softening plant is of the greatest importance, because the efficiency of the boiler plant, its evaporative power, its ability to work at full capacity with a minimum of cleaning, and the life of the steam-raising apparatus, depend upon the thoroughness with which the softening process is conducted. As a general rule, 1½ pounds of pure soda ash are required to soften every thousand gallons of water when this has a permanent hardness of 10 degrees.

There are various types of apparatus for removing the oil from feed water, but on board ship the pressure type of filter is generally used. This consists of a long length of towelling secured to perforated cylinders. The oil is arrested by pumping the condensate through the special filter cloth. Filter cloths should be renewed every ten days, and the dirty towelling boiled in a tank—or, a 10-gallon iron oil drum that has been thoroughly cleaned will answer the purpose very well. About a pound of soda, 2 ounces of caustic soda, and ½ pound of good soft soap are dissolved in the amount of water required to fill a 10-gallon drum, by inserting a drain pipe attached to the steam chest of an auxiliary, such as a feed pump, and boiling the solution by passing steam through it. When the liquid is boiling, the filter cloth is put into the tank and gently boiled for twenty-four hours. Then the cloth is removed and, after being thoroughly "wrung," is washed in at least three lots of ordinary boiling water.

On shore the oil separator generally consists of a steel tank containing a large area of patent baffling plates. The simplest method of cleaning these is to introduce a sufficient quantity of washing soda, with a small addition of caustic soda, and to fill the tank full of water. By fitting a small steam connection to the shell and connecting a suitably perforated internal pipe, the contents may be thoroughly boiled for twenty-four hours. After the boiling process the separator must be washed out with a copious supply of hot fresh water. When the apparatus is started up once more the drain should be frequently opened to make sure that the apparatus is in proper working order.

In the case of feed water oil filters which work under pressure, the water must be run into the container very slowly, and the small cock fitted to the cover must be left open, so that all the air displaced by the rising water may freely escape.

(c) *Heating Plant.*—Contact feed water heaters, in which the exhaust steam is mixed with the water to be heated, often have a considerable amount of froth and scum floating on the surface of the water. If the steam contains any oil in suspension it must, as already explained, first be passed through a de-oiler. If this precaution has been observed, the scum will be due to impurities in the water. As a general rule, if exhaust steam is available for heating the feed water, and a plant is provided with a water softener, this apparatus fulfils the combined duties of feed water softener and heater, but often the softening plant is a rather crude home-made affair, and the main work of purifying the water is performed by an exhaust steam feed-water heater. In this case the calcium carbonate, for instance, may be entirely removed if sufficient exhaust steam is available. A feed water that has very little permanent hardness, but a considerable amount of temporary hardness, may be treated in this way only, but the internal parts of the heater must be occasionally cleaned to free them from scale. The outlet pipes may become partially choked, which will mean that the velocity of the water through them will be higher than it should be, and a considerable quantity of scale-forming matter may be carried into the feed-pipe range. A slow movement of the water will allow the sediment to settle before it reaches those parts of the system which should not accumulate scale.

If a surface feed heater is fitted with an internal splash box or tray, this must be properly cleaned to ensure that the holes are perfectly clear and the fixture is not corroded. The steam in heating the water liberates the air imprisoned therein, and the oxygen thus freed may cause rapid corrosion. As it is essential that a regular supply of feed water should be maintained at all times, the heater is worthy of a little better attention than in most cases it receives.

The exhaust steam pipes frequently corrode, and allow steam to escape to atmosphere instead of sending it all into the heater. Heat and water are thus wasted. The silent working of heating apparatus is often desirable, but introducing the exhaust steam below the water-level does not improve conditions in this respect. The only effective method of silencing is to break up the steam into fine particles by allowing it to impinge on a perforated plate.

All contact feed heaters must be fitted with a pipe to allow all the air to escape, and it is imperative that this pipe should be in a proper condition.

If any grease collects in the feed-water heater owing to the faulty action of some piece of apparatus, the interior of the heater must be thoroughly cleaned. None of this injurious matter must be allowed to find its way into the boiler, where it will undergo decomposition when boiled, liberating corrosive liquids such as stearic acids.

Surface feed heaters are invariably used where the steam used to heat the water is of a high pressure or very greasy. The object in both cases is to keep the feed water separate from the steam, and all the tube joints must therefore be absolutely tight, and to secure a maximum transmission of heat through the tubes the surface must be very clean. If the joints are not tight, the feed water will be contaminated by the impurities in the steam, and the whole purpose of using a surface feed heater will be defeated.

The ordinary feed heater is constructed on the same principle as a surface condenser, a large number of tubes pass through two tube plates, and a tight joint is obtained by using suitable packing held tight on to the tube by stout brass ferrules. The packing may become dry and cause leakage, in which case the tubes must be repacked. Before the feed heater is closed up, it should be filled with water, and the tube ends carefully examined to see that they are all tight.

In most designs of feed water heaters the water passes round the outside of the tubes, but in types in which the water passes through the tubes the inside surfaces may become coated with a film of grease, and this is frequently difficult to remove. It must be removed, because otherwise the efficiency of the apparatus will suffer. The simplest method of removal is to pass a stout tube-cleaning brush through each tube, and afterwards to flush the tubes through with a hot solution of soda and water. This type of heater is only suitable for heating distilled water, or condensed steam, but negligence is often displayed in this respect, especially if a large amount of "make up" feed water is passed through the heater without previously having been softened. As a consequence of the negligence, a considerable amount of scale may form on the outsides of the tubes, and this can only be removed by taking all the tubes out and "pickling" them.

Surface feed-water heaters are generally lagged with composition and covered with sheet steel. The lagging must be in good condition, and should cover the heater completely. Very often only a thin coating is applied, and too much reliance is placed on the layer of air between the lagging and the steel sheets. It is essential that the heater should be well lagged on account of its large surface, all of which will otherwise radiate some of the heat which has just been given to the feed water, and, of course, it is uneconomical to deprive the water of heat before it reaches the boiler. This type of feed heater is liable to galvanic corrosion, due to the different metals, such as brass, cast-iron, and steel, which are used in its construction. Because it is frequently placed between the boiler feed pump and the boiler in modern high-pressure plants, it takes the place of the economizer and the engineer-chemist must examine it as carefully as he does the boilers themselves.

If the feed-pipe range is not supplied with a reliable safety-valve, the feed heater must have one attached, so that undue accumulation of pressure will be prevented by overflow in case all the boiler feed check valves are shut, and the pump is not stopped. This fitting must be cleaned and overhauled, as well as any valves which may be attached to the heater itself.

CHAPTER XXIII

PIPE LINES

(*a*) *Pipes and Joints.*—The two most important items connected with pipes and joints are the safety of the pipe range - that is, the effectiveness of the supports—and the condition of the insulating material with which they are covered.

It is a common occurrence to see indefinite lengths of pipe floating unsupported, and hanging in the most alarming catenary curves. All pipes must be adequately supported, and although the methods of support vary considerably, one essential requirement is that the pipe must be free to expand.

Different methods of supporting pipes were illustrated in Chapter XI. From time to time the supports should be examined. Roller bearings should be cleaned, the roller oiled, and tried by hand to make sure that it moves freely. Rollers frequently stick, and the pipe, owing to vibration as much as to expansion, rubs against the roller, which is unable to move, with the result that a flat surface is worn on the pipe.

Pipes are frequently supported by hangers made of flat sectional iron. Such hangers should be so fixed that the flat surface of the steel hanger above the part forming the actual clamp is parallel to the face of the flange, and that any expansion of the pipe—that is, any movement in the direction of the pipe - will tend to bend the flat metal. If the metal is "end on," and the upper part is not bent through 90°, the resulting very rigid joint will not "give" when the pipe expands.

The high-pressure steam pipes must be lined up from the boiler stop-valve, and if there are any joints which continually give trouble, it is almost certain that the pipes are out of line. If the flanges are all machined and can be relied upon, alignment is very easy, and only involves the proper use of a set of testers or feelers. If, however, the flanges are rough, or have been machined "anyhow," and are not square with the pipe, the job is very trying. Each pipe must be set to a steel wire stretched through the centre of the pipe. If the pipes are curved the best course—which pays in the long run every time - is to take them down and reface them in the machine shop.

Another item that is often a cause of worry and delay when repair work is in progress, or slight alterations are being made in the existing pipe line, is the pitching of the bolt holes and the number of holes in the flanges. Since the introduction of the British Standard Tables matters have improved considerably, but it still happens that makers drill the flanges of valves and pipes according to their own tables.

Cast-iron water pipes frequently have the holes cast in the flange, and the pitch circle in some instances is not true; and for a variety of other reasons, valves and pipes cannot be relied upon to fit together as they should. Consequently, flanges must be marked off when in place, or a template must be made. Making a special template is a costly and, therefore, undesirable operation, and should only be necessary in cases where the valve or other piece of apparatus is too heavy or unhandy to be brought temporarily into the correct position for marking off the bolt holes.

Different manufacturers adopt different diameters of flanges for the same size fitting, and the diameter of the pitch circle varies accordingly. The greatest care is therefore necessary when ordering fittings or pipes which are to be delivered with the flanges ready drilled, and the prudent engineer-chemist always encloses with his order an exactly drawn small sketch, showing whether the bolt holes are off the centre or not. A common mistake is to compare the sizes required with those given in a maker's catalogue, but to forget that the position of the valve spindle must be taken into account when considering whether the holes drilled in the new flange will correspond with those in the old flange to which it is to be fitted.

When pipes are being put up they should not be forced until the flanges—that is, the bolt holes—are " fair," or opposite each other. In some establishments it is the recognized practice when putting up copper pipes to insert two—or, if possible, three—bolts in each flange, and then to pull the pipe into position. This operation is technically known as springing the pipe, and although it is possible in the case of copper pipes, subject to the risk of damaging the brazing round the flange, it is not so easily done in the case of steel or cast-iron. Very long steel pipes can be sprung into position with the assistance of a pair of chain blocks. It must be remembered that the pipe is not permanently bent—the steel is too strong for that—but it is distorted exactly in the same way as a piece of piano wire may be bent in the ordinary meaning of the word. It springs back into its original shape when released. Steel pipes which have been at work under pressure for ten years have to be sprung into position again after being disconnected for the insurance company's hydraulic safety test.

The question of springing pipes has been introduced to emphasize the extreme undesirability of subjecting pipes to unnecessary stresses. Steam-pipe explosions are unfortunately not rare, and in ninety out of every hundred cases the pipe, considered solely as a cylindrical vessel, was of ample strength at the time of the explosion. It is the additional stresses, such as those due to springing, water-hammer, or inability to expand freely, which, being greater than the stress produced by the internal pressure of the working fluid, cause the metal to fail. Pipes which are subjected to vibration often fail in consequence of the deterioration of the mechanical properties of the metal through fatigue.

Pipes frequently crack round the flanges, and, as often as not, the reason is faulty jointing. The best practice is to scrape the faces of the flanges until the surface, when tried with a face plate, shows that when bolted up they will make a steam-tight joint. A thin application of red lead paint is all that is required for a perfect job. This procedure is out of the question in commercial power plants on account of the expense. The next best plan is to machine the flanges, and to use good steam jointing $\frac{1}{32}$ inch thick; and this should be adopted as the standard.

Many steam-pipe flanges are never machined, and in order to overcome irregularities, a very thick joint is made, or patent corrugated metal rings copiously covered with black cement are used. When such joints have to be broken—and they all start leaking sooner or later—the flanges must be filed true, and good steam jointing used. The jointing should be covered with a little graphite to prevent the joint sticking to the flange, and thus causing needless labour when the joint has for any reason to be broken again.

Fig. 240 shows two methods of making a joint. The right-hand illustration indicates correct practice—a joint the same size as the flange.

The left-hand drawing shows a metal ring—copper rings are often used—placed inside the bolt circle. When a joint thus made is tightened up, excessive leverage is exerted on the flanges, and if the pipe is subjected to a violent shock or other disturbance a fracture may occur, because the flanges are not face to face, but a narrow bearing surface, the width of the metal ring, is all that is available to take the pressure.

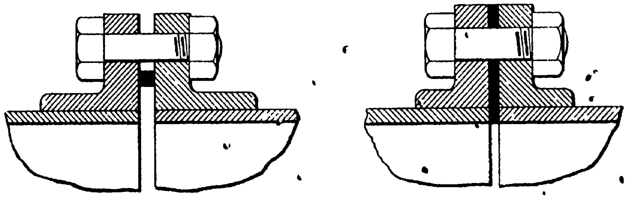

FIG. 240.—PIPE JOINTS

The condition of the steam-pipe range is generally a good criterion of the manner in which the whole plant is kept. In this connection the engineer-chemist should remember that wooden wedges can be put to other uses than for stopping leaky pipe joints—quite apart from any question of beauty.

(b) *Attention to Lagging.*—A few remarks about lagging were made when dealing with boiler covering, but, important as that is, the need for covering *pipes* in a proper manner, so that a minimum amount of heat shall be lost by conduction, is even greater.

There are different methods of covering pipes. Materials that have been tried include slag wool, loam, cork, felt, asbestos, fossil meal, magnesia, and a large number of cheap compositions containing in most cases some of these ingredients in varying proportions. The efficiency of any covering depends on porosity, or cellular construction. The quantity of air contained in its tiny cells is the real measure of the insulating value of any material. For this reason hair felt is about the best covering procurable, but owing to its high cost and the facts that a considerable thickness is required, and a suitable protective covering must be supplied in addition to the felt itself, this material is not much used for pipe lagging. It is, however, employed for insulating various kinds of apparatus. Evaporators, pumps, feed-heaters, etc., are generally finished with a covering of planished steel to improve their appearance; in former days polished mahogany was largely used. The space between the steel covering and the casting can advantageously be filled with hair felt.

Much of the surprising negligence which prevails to-day with regard to the proper covering of pipes is no doubt due to the fact that the heat wasted through bad lagging is lost unseen. A leaking joint is a phenomenon which can be seen, but there is no visual indication of the quantity of heat being lost. In certain cases, however, the wasted heat can be felt—as, for instance, in the engine room of a ship. This fact no doubt explains why the pipe systems in the engine rooms of ships are fairly well covered with insulating material.

Pipes are frequently covered with inferior covering which has a comparatively low efficiency. Over and over again, when an entire pipe system has been covered in a proper manner, the temperature of the engine room has fallen from 15° to 20°. Engineers who have served on board ship in the tropics will realize the enormous difference such a reduction in temperature makes in comfort, turning a four-hour watch from a seemingly endless spell of torture into a more or less bearable period of duty.

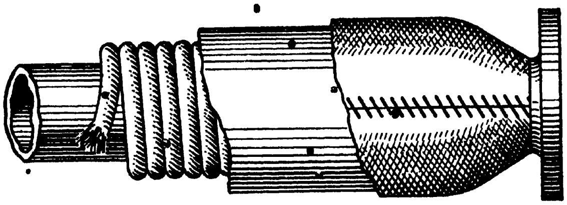

FIG. 241.—PIPE COVERING.

The fact nevertheless remains, that all steam pipes dissipate heat, and that the loss increases as the difference between the temperature of the steam inside the pipe and the surrounding air becomes greater. Pipes in the open—or in boiler houses the temperature of which is but a few degrees above the outside temperature, owing to the very " open " construction—lose a very large amount of heat by conduction, although the loss does not actually " make itself felt." If it were easy to form a vivid mental picture of the discomfort which would be experienced by human beings condemned to spend their time in proximity to the pipes in a room totally enclosed, and not open to fresh currents of air, the significance of wasted heat would be better realized, and the subject of pipe-covering would no doubt receive more attention.

Magnesia composition containing 85 per cent. magnesia is a very reliable covering material, but in some instances the cost is rather heavy, as the substance is not always readily obtainable.

The writer has made a careful study of the subject for the purpose of finding a covering which is durable, can be obtained in most parts of the world, and gives maximum efficiency for minimum cost. Practical experience has proved that a pipe covered as shown in fig. 241 will give satisfactory results.

The pipe is first thoroughly cleaned, and painted with a coat of good thick lead paint. When the paint is perfectly dry, an asbestos rope of superior quality is wound tightly round the pipe.

The importance of using strong asbestos rope and not the inferior "filled" variety must here be emphasized. "Filled" rope consists of a thin outer covering of asbestos, the interior being filled with a loose material which undergoes disintegration when it is heated, and is reduced to a powder. It is a waste of money to buy such rope.

When the asbestos rope has been wound tightly round the pipe, and each turn has been beaten down with a wooden mallet, the entire surface is covered with magnesia composition with a minimum thickness of ½ inch. This covering must not be applied with a trowel, but actually thrown on to the pipe in small pieces. This part of the work may be done with steam in the pipe, so that each little lump of magnesia will bind with the remainder to form a solid covering. The lagging may be smoothed over to make a good finish.

After the composition has set, and there are no signs of cracks anywhere, good thick asbestos cloth is neatly laid round the pipe, and sewn together with asbestos yarn. This latter item is very important, because ordinary twine soon becomes rotten, and the stitches break. For the same reason ordinary canvas must not be used.

At the end of the pipe the covering should taper away so that the bolts may easily be inserted in the flange. In many cases the covering is taken right up to the flange, and when a fitter has to take out the bolts to remake a leaky joint, he breaks away some of the covering, which gives the pipe an untidy appearance.

Considerable controversy still rages around the question of covering the flanges. Theoretically all flanges should be covered, because they radiate heat, but the practical man prefers to be able to see all the joints, and to know that they are tight. If flanges are to be covered, this must be done in such a manner that the lagging can easily be removed. To comply with the condition a small cover may be made which can be secured with hooks and eyes. In the best practice either an arrangement of this sort or a flange box is fitted.

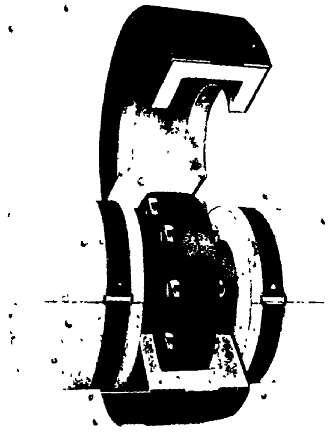

FIG. 242.—FLANGE BOX.

Fig. 242 shows a flange box made by Messrs. Newalls, and so constructed that it can easily be removed for purposes of inspecting the pipe joint.

All pipes, however well they are lagged, must be covered with at least two coats of paint, if subjected to wind and weather. Pipes lagged with ordinary composition must be painted with good tar paint to protect the composition from becoming soaked when it rains.

Fig. 243 shows the boilers and steam and water pipes of a large Lancashire boiler plant lagged with Newall's covering.

In boiler plants which have a very complicated system of piping, the pipes may be painted in distinctive colours according to their functions, so that a live steam pipe may easily be distinguished from an exhaust steam pipe, an ordinary water main from a feed water range, etc.

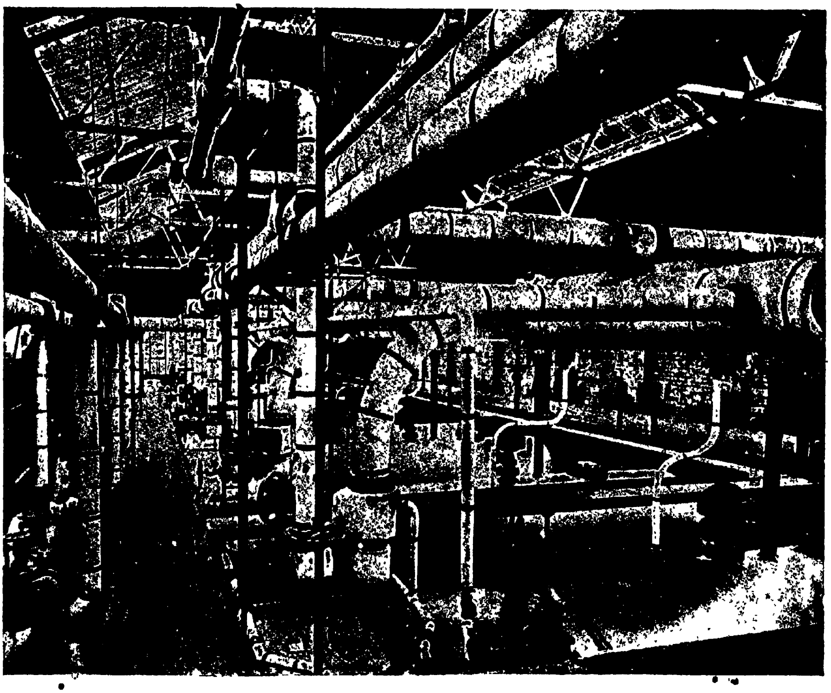

FIG. 243.—EFFICIENT PIPE LAGGING.

(c) *Valves, Steam Traps, etc.*—There are a very large number of valves on the market, but comparatively few are worth buying. In support of this statement it may be mentioned that the number of steam stop-valve explosions since 1919 is increasing in a most alarming manner.

High-pressure steam stop-valves require to be cared for with the same thoroughness as boilers, and all other valves need attention according to their duties. The reader will recall the similar remark made when dealing with boiler mountings.

Full way or sluice type valves are largely used on shore, because they are considered safer. The stresses set up in the casting are not so severe as with the ordinary globe type of valve, and water pockets are not so likely to be formed. These valves, however, are difficult to keep tight, unless specially designed, and a well-designed globe valve constructed of the best materials will give more satisfaction.

Valves containing parts made of gunmetal and brass must never be used for superheated steam, but a cast-steel valve body fitted with nickel steel valves and seats will give good service

All valves should be tried once a week to make sure that they are in a good condition, and can easily be operated.

Valves on the tops of boilers frequently become covered with soot and, because gritty particles find their way into the glands every time the valves are operated, the spindles become worn and steam leaks are the result. A simple cover, as shown in fig. 244, may easily be made from a small piece of canvas, or a sack cut to the required length can be used as a cheap substitute

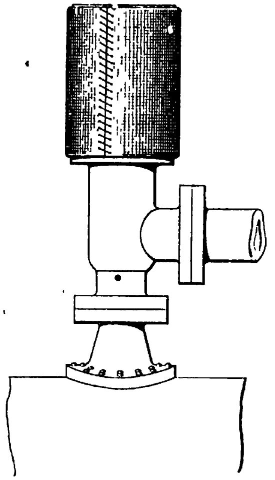

FIG 244 —CANVAS COVER OVER VALVE TO PROTECT IT FROM DIRT

If a valve has to be operated in a hurry in case of an emergency, the cover can be ripped off, and the valve that has been so covered will be easy to work, as compared with one which is covered with dirt and the wheel of which is hard to turn, because the hard and gritty packing firmly grips the valve spindle.

If a valve leaks, arrangements must be made to open it up while using the alternative pipe system, and the opportunity must be taken to give the valve a general overhauling It frequently happens that a steam valve requires a little attention, and whilst the repair immediately required is being made, a more important defect is overlooked, because it is not connected with the work actually in hand. When, for example, a boiler is to be cleaned, but it is found that the steam junction valve leaks so badly that it is impossible for men to work in the boiler, arrangements have to be made for the valve to be repaired before anything else can be done, and this usually involves loss of time. Few things are more annoying than to find, after relying on a valve to be steam-tight, that it leaks so badly that the particular section affected by it cannot be properly isolated.

Generally valves only require to be re-ground or, if they are in very bad condition, skimmed up in the lathe. Details of this work were given in Chapter XXI. (see p. 289).

Very large gate or sluice valves are sometimes fitted in exhaust steam-pipe ranges, and as the mechanism for opening and closing these valves is often complicated and operates in an indirect manner, as in the case of valves fitted with bevel gearing, it is absolutely imperative to have a tell-tale arrangement, so that by looking at an indicator the attendant can see whether the valve is open or shut.

Steam traps are of two kinds—viz., thermostatic and float. In the former type the condensed steam is discharged by mechanism, the operation of which depends on a reduction in the temperature of the steam, whilst in the latter the discharge is regulated by a float.

The traps are automatic and, like other similar apparatus, can give endless trouble. The float type gives the best results, and if the choice of such apparatus rests with the engineer-chemist he will see that only such apparatus is installed as has proved its value under running conditions. Steam traps must be of the simplest design and very rugged in construction, with a minimum of working parts. Otherwise the maintenance charges will be out of proportion to the usefulness of the apparatus. The traps should come under the supervision of the works maintenance department, and in that case the engineer-chemist will only have to see that all the exhaust steam which can again be utilized for feeding the boilers is returned to the boiler house.

CHAPTER XXIV

STRUCTURAL REPAIRS

(*a*) *Fuel-Handling Plant.*—Fuel-handling plant and bunkers are the two most important items that have to be considered in the present chapter, so far as maintenance is concerned. The machinery for transporting and weighing the fuel requires periodical examination and overhauling, because it works under somewhat disadvantageous conditions, due to the continual presence of dust. Bunkers deteriorate, partly because the fuel is frequently wet, and partly as a result of the peculiar characteristics of coal.

The fuel-handling plant will include weighbridge, or automatic weighing machinery such as an automatic tipping machine or a continuous weighing machine. The ordinary type of weighbridge should be cleaned and oiled once every six months, and tested for accuracy every three months. Many firms have a contract with the makers, who send a representative periodically to examine, repair, and see that the machine is in proper working order This will be found to be the most economical practice in the long run.

If a private test is to be made, the simplest method is to use a tank of known weight, and fill it with a quantity of water whose volume can be calculated.

Weighbridges, as a rule, give little trouble unless they are very old, in which case the balancing mechanism and lever system may be sluggish in responding to the balancing weight.

Fuel elevators and conveyers are generally designed in such a manner that they are worked by totally enclosed electric motors, but belt driven elevator shafts are still to be seen. The repairs needed are generally small and of a miscellaneous character, but it is essential to have a weekly inspection, because if the fuel-handling plant breaks down, and the bunkers are only large enough to provide for the immediate needs of the boilers, a serious stoppage may result.

Here we have a good illustration of the vital importance of reliability in the subsidiary plant, because in large boiler houses the alternative of handling the fuel by hand is out of the question. Not only is the volume too large, but the structural design of the building does not allow of such procedure being adopted in emergency. Central power stations are generally equipped with two or more automatic telphers or conveyers, but fuel-handling plant as installed in the power houses of large factories is seldom in duplicate.

Travelling cranes, grabs operated from telphers, belt conveyers and similar machinery, are operated electrically, and the motors should be examined at least once a week, and more often if their design necessitates very careful examination.

Some makers fit small mica-covered inspection doors to their motors. Often the mica becomes so dirty that it does not serve the purpose for which it was intended, and the machine is neglected or the windows become broken and coal dust settles on the commutator. When this takes place, the commutator soon suffers, and the motor sparks very badly, so badly that the effect is often to produce continual illumination.

It has already been said that mechanical stokers are generally supplied with fuel from overhead bunkers, and that such bunkers are made of steel plates. The steel is subject to rapid corrosion, because the fuel is often wet when the bunkers are filled, and also because coal undergoes "weathering," which is a process of slow oxidation. Incidentally coal is liable to become heated to such an extent as to cause spontaneous combustion. Generally speaking, the fuel does not remain in the bunkers long enough for this to occur, but on board ship, where the coal lies in bunkers which form an enclosed space and are frequently badly ventilated, great trouble is experienced when the coal commences to burn.

Bunkers should be well ventilated so that the temperature will always be about the same as that of the atmosphere, and on no account must facilities exist for an explosive mixture of air and gas to collect in pockets.

The slow oxidation of coal may be compared to low temperature combustion, and in both cases the coal loses some of its calorific value. If coal is stored for a long period under atmospheric conditions it may lose as much as a third of its heating value.

Firms which keep large reserve supplies against industrial disturbances also run the risk of spontaneous combustion, because the heat produced by the slow oxidation cannot readily escape and therefore increases the temperature inside the heap. If large reserve supplies of fuel are kept, the engineer-chemist will see that the fuel is stored in comparatively small heaps, and that proper precautions are taken by placing pipes for temperature-taking purposes in position before the coal is dumped.

From the foregoing remarks it will be gathered that overhead bunkers should be constructed in such a manner that no coal can collect in any pockets. If the bunkers are badly designed, steel plates must be fitted so that the coal will fall easily towards the outlet. It is better to reduce the capacity of the bunker slightly than to run the risk of the coal catching fire. In some cases the bunkers are exposed to heat due to the bad ventilation of the boiler house or to their proximity to flues and economizers, especially when these are placed high above the ground. Such conditions are most favourable to spontaneous combustion.

The steelwork of the bunker should once a year be thoroughly chipped, cleaned with a wire brush, and painted. The inside of bunkers is best protected by covering with a good bitumastic solution. If the bitumastic is applied hot, as it should be, the plates should be corrosion-proof for a number of years.

The care of overhead bunkers is rather more important than is generally recognized—firstly, because a very heavy weight is supported by the bunker, and secondly, because once the plates begin to corrode, it is exceedingly difficult to arrest the process. It is now well known that when rusting has once commenced, the presence of moisture is not necessary for its continuance. This, of course, means that although a rusted plate is superficially cleaned, and even painted, little reliance can be placed in its future behaviour. Hence concrete is replacing steel as a constructional material in connection with coal storage. Concrete fuel bins can be built any shape, the surface can be given a smooth finish so that the fuel falls easily, and the all-important factor of corrosion is eliminated. Another advantage of concrete construction is here worthy of notice. Steel girders, etc., will buckle if subjected to intense heat, such as is experienced in a fire due to spontaneous combustion of coal, but reinforced concrete has great fire-resisting qualities Thus there are at least two good reasons why reinforced concrete is superseding unprotected steel in boiler-house construction, including the construction of overhead bunkers

Before leaving the subject of fuel handling, it may be worth while to refer to the special study which has been made of this subject in the United States. With winter temperatures often falling below zero and hovering around that figure for weeks at a time, the problem of the coal supply is a very serious one for our American cousins, particularly in manufacturing districts, like the textile area of New England, which are several hundred miles away from the nearest coalfield. Both the mines and the railways are subject to industrial warfare of the bitterest kind, and it is therefore customary for large plants and railways which have no direct access to the coalfields to accumulate enormous reserve stocks of fuel

Even in plants with comparatively small requirements the coal piles have been of sufficient size to cause disastrous fires when spontaneous combustion occurred. In November, 1918, a large plant engaged in aeroplane manufacture at Marblehead, in the State of Massachusetts, was completely destroyed, and although several theories were advanced to account for the fire, the only positive piece of evidence was that a stock of coal, amounting to about 100 tons, had been found on fire in the boiler house three or four weeks earlier, and that this had been rehandled and piled against the wall of the building in which the fire started. About 75 tons remained in the pile on the day of the fire. Some months earlier the National Fire Protection Association[1] reported a fire in which part of a papermaking plant was reduced to ashes as the result of spontaneous combustion in a pile of coal banked against the wall of a building. In the light of such experiences it is not surprising to find the United States Bureau of Mines giving serious attention to this matter.

The investigations of experts have led to methods of storage with which Englishmen are unfamiliar For example, about six years ago the Duquesne Light Company of Pittsburg constructed a concrete-lined pit 800 feet long, 150 feet wide, and 25 feet deep, for the safe storage of 100,000 tons of coal, which was to be kept constantly submerged in water to avoid the risk of spontaneous heating.

If coal is not totally submerged, the less moisture it contains the safer will be its storage in large quantities. So with ventilation, unless it can be sufficiently thorough to ensure that air reaches every part of the pile it is better to exclude air altogether. Piles of large area should be subdivided, and the height of the pile should not exceed a few feet. Storage in bins with air-tight bottom has been found to possess distinct advantages as compared with covering the surface of the coal. Coals with high sulphur content in the form of pyrites are stated to give special trouble, owing to the development of sulphuric acid in the weathering of iron pyrite. It is considered desirable to take the temperature of the pile twice a week for the first three months, by lowering thermometers to various depths in pipes similar to those recommended above (p. 309); after a pile has been in existence for that period a weekly temperature-taking will suffice. Experiments are in progress to determine the relative liability to spontaneous combustion of the various types of soft coal mined in the United States.

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[1] *National Fire Protection Association Quarterly*, vol xii, No. 1, p 108

As soon as he finds a temperature of 150° F., the engineer-chemist is warned to make preparations for removal, and when 180° F. is reached the rehandling should be commenced. The work must be done scientifically, and not haphazard, for if the rehandling is not so conducted as to effect a thorough cooling of the heated fuel, the last state will be worse than the first.

Dr. von Schwartz, the great authority on the chemistry of fires, had many years ago laid it down that gentle protracted warmth of, say, 85° to 100° F., would create a very dangerous condition in a coal store, and the truth of his dictum has been verified by many a painful experience on board ship, where the coal has to be stored in close proximity to the boilers, and in warm climates on land. The presence of slack and fine coal in any quantity also increases the hazard of spontaneous combustion, and when, as sometimes happens on shipboard, violent movement sets up a grinding action, the pulverization thus brought about may become a source of danger.

(*b*) *Buildings*.—Machinery which is to be kept in good condition and running order must be suitably protected from wind and weather. Insufficient attention is given to the housing of power plants in this country, and a very large number of British boiler plants work in the open.

The engineer-chemist will be responsible for keeping the property on which the power plant stands in good condition, and he will therefore make such examination as he may think necessary. First to be considered are the foundations, which must be carefully watched for any signs of subsidence. The conditions of a boiler house are different from those of any other building, because a certain amount of the heat generated in the boilers is lost by conduction, and this heat is largely absorbed by the ground. Extra heavy rainstorms or the overflowing of a river can have the most unexpected effect on the foundations of a boiler house, because the weight supported by every square foot is fairly high. The first indication of subsidence generally takes the form of cracks in the brick walls, but sometimes the walls get out of plumb before any cracks appear. Cracks running in a horizontal direction are not very serious, but a zigzag crack needs careful investigation.

Alterations to the existing buildings are often a source of much trouble, inasmuch as the foundations will not take the extra load imposed. This has frequently been the case when an old boiler has been replaced by a new one of slightly larger size.

The masonry of the buildings is sometimes defective, and since the walls often support, in addition to the roof, very heavy loads—such as economizer, overhead bunkers, etc.—their condition may well call for thorough inspection.

Modern boiler houses are built of steel. In other words, the framework which takes the principal loads is built of steel beams, and the walls only serve the purpose of closing up the framework. Such construction is suitable, because if the foundations for the main supports are taken down to a sufficient depth to ensure perfect safety the behaviour of the walls need not be a source of grave anxiety.

There are many so-called boiler houses which consist of two small side walls (generally in a dilapidated condition), a back wall composed of the bunkers, and a corroded corrugated iron roof. The moral of firemen working under such conditions is not conducive to the best results. The men become hot when working the fires, and in the short intervals between their arduous duties they are exposed to cold draught and possibly rain. Little wonder they stay away from work, complaining of rheumatism and other ills. It is hard to imagine scientific instruments indicating maximum efficiency and an organized system of fuel economy under such primitive conditions.

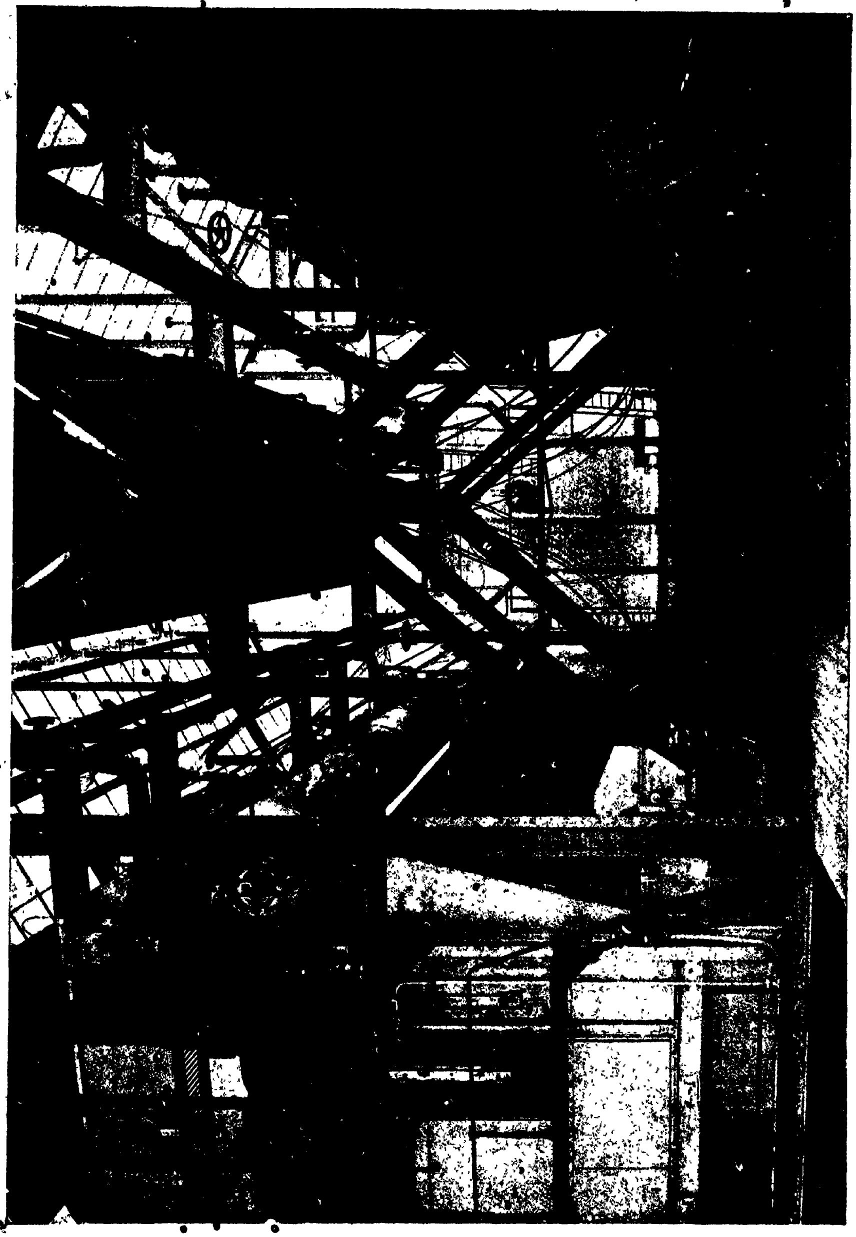
The lighting of the boiler house is also important. There are boiler houses which are lighted on the most modern lines, every detail having been carefully studied, but there are others working underground and illuminated by a few small gas jets supplemented by oil lamps. Although the eye is spared the painful sight of neglect which must necessarily follow such working conditions, it is wonderful to think that men will toil under such disadvantages. Most of the faults in a boiler house must be detected by the eye, and where the satisfactory operation and maintenance of the plant depend on a good memory and an ill-founded trust that the unseen will not give trouble, the risk of a breakdown is very great.

It is somewhat curious that the question of ventilation is frequently overlooked in modern boiler houses which in all other respects incorporate in their design the very latest practice. There are occasions when smoke and noxious fumes are formed in the boiler house even though boilers are fired by mechanical stokers, and provision should be made for these to escape through openings in the roof. This is the more important because such fumes are generally corrosive, and should therefore not be allowed to condense on the cold steelwork of the roof, etc.

Where overhead bunkers serve the boilers, the height of the buildings is ample, but in Lancashire boiler plants the height is frequently so inadequate that special arrangements have to be made for the main steam pipes to clear the roof trusses. There is no excuse for such a state of affairs.

In cases where pipes pass through the walls of the building, it is common practice to make holes and fill the gaps afterwards with bags, etc., the result being most unsightly. The pipe should, of course, not be surrounded by brick which will interfere with its easy expansion, but a suitable piece of wood, cut in halves and fitted round the pipe, will prevent cold air rushing past the pipe and incidentally make a neat job.

The steel structure of a boiler house should be thoroughly cleaned and painted at least every two years. Only too often it is argued that paint is not required in



a boiler house—and it certainly is not, from an æsthetic point of view, in boiler houses as they exist to-day; but iron and steel corrode quickly, and the conditions in boiler houses are exceedingly favourable to corrosion. Paint has, therefore, a very real protective value. Fig. 245 shows the interior of a modern boiler house, and demonstrates that a high, airy, well lighted, pleasant boiler house is quite possible.

Some boiler houses are very draughty. This is a very undesirable condition, because not only do the boilers suffer from a fluctuating temperature, but dust flies about everywhere, and the attendants complain. The welfare of the staff is not considered as seriously as it should be, because the all-round lack of interest in the boiler house operates also to the detriment of those who work therein. One of the great changes which are long overdue will mean the employment of the right type of man, paying him accordingly, and looking after his self respect by providing suitable accommodation where he may change into working clothes, have a wash and sit down during the meal hour when he snatches a hurried bite and keeps a sharp eye on the gauge glass. Some firms have a corner of the boiler house reserved for this purpose, but in the great majority of cases the conditions under which the men work are positively disgraceful. Yet wonder is expressed why firemen are such a "rough lot."

The firemen use raw materials worth thousands of pounds, and they should therefore be chosen from men who realize the responsibility of their position, and can be expected to know their job. In large boiler houses where the boilers are fired by mechanical stokers, the old fashioned combination of brute force and ignorance is no longer serviceable, and attending a boiler is a refined performance, requiring skill if the results are to be good. It may still be called a dirty job because dust cannot be eliminated, but the men must have brains, and if better working conditions, in the shape of comfort such as the other factory employees enjoy, existed in the boiler house, a different type of man could be obtained, and the boiler-house world would be revolutionized. In America there are boiler houses where the firemen are senior to the engine men, and although by no means pampered with a lot of so-called "welfare" work they are recognized as human beings who expect to work under conditions in keeping with the responsibilities of their job.

CHAPTER XXV

CONCLUSION

ALTHOUGH fundamental principles of good management are the same for the largest as for the smallest plant, it is obvious that the method of presenting those principles will be influenced by the particular type of plant which occupies the forefront of a writer's mind. It will have been apparent from the earliest chapters that the present work has been planned and written with special reference to the needs of average industrial boiler plants and of ships of the mercantile marine. The author has drawn upon his experience afloat and ashore for suggestions and practical illustrations that should appeal with equal force to the company director and the plant engineer. For the benefit of the director he has indicated the financial advantages of utilizing to the full the heating value of all fuel consumed, and in dealing with the technical aspects of steam production it has been his constant aim to be of service to the engineer who has to solve the every-day problems of management.

What may be termed extraordinary plants as, for example, abnormally large water-tube boilers fired with pulverized fuel have received only incidental consideration. Every such plant employs a staff of experts, and its operation involves the use of special methods and apparatus having a literature of their own.

The vast majority of British factories are supplied with power by boiler plants consisting of a number of Lancashire or water-tube boilers, and upon the efficiency of these factories the welfare of British industry depends. Even British agriculture, which is notoriously conservative and individualistic in its methods, is now largely dependent on factory efficiency, as agricultural machines are used to a much greater extent than was formerly the case. The non-agricultural population is entirely dependent, directly or indirectly, on the type of industry represented by the factory.

A factory organization which manufactures articles at a lower cost than its competitors, and is willing to fix the selling price accordingly, will always be busy. A large number of workers will be continuously in employment, and their purchasing power will help to keep other industries busy.

On the manufacturing side of most factories technical efficiency is high, and interest is maintained in the development of improved methods of production. In so far as the efficiency of the boiler plant falls below the level attained by the remainder of the factory, the net percentage of efficiency is decreased. The keen competition between craftsmen makes it very difficult to effect substantial relative economies in manufacturing processes, but in the field of steam production, where scientific management is the exception rather than the rule, important savings are easily possible. Much can also be done by utilizing more efficiently the steam actually supplied, but that is a topic beyond the scope of this book.

Fuel—chiefly raw coal—is the mainstay of British industry, because it is used in producing the energy required to keep the factories working, whether that energy is consumed in the form of steam, mechanical power, or electricity. The scientific control of the boiler house to obtain the maximum energy from every pound of fuel burnt is therefore of vital importance.

When a super-power station or a super-Dreadnought has been completed, either of which may represent a paltry 150,000 horse-power, the public is advised of the fact by the daily and technical press. This is quite in order, because the very fact that such formidable tasks have been completed is proof of the ability of British engineers, and it is pleasing to know that the inventor's mind has once again surmounted the difficulties that undertakings of this character always present. The very considerable quantity of fuel necessary to operate a super-power station or a super-Dreadnought will probably be consumed very economically under the supervision of highly trained men, and this is all to the good. But the total horse-power of a super-Dreadnought is vastly less than that of all the Lancashire and water-tube boilers manufactured during the period of construction of the great ship. The fuel consumption of most of these boilers is habitually wasteful; but because the topic has no "news value," the public is never made to realize how serious is the loss involved in the inefficient operation of the ordinary plant. It may help the reader to a better realization of the importance of the small power unit to know that the horse-power of the motor cars annually turned out by the Ford works is greater than the combined horse-power on board the ships of a battle cruiser squadron.

Naturally, this leads us to the question, What can be done to promote good management of ordinary factory boilers? During the present year (1923) a serious start has been made towards solving the problem of smoke abatement, and the abolition of the smoke nuisance can mean nothing else than that fuel which is now permitted to escape into the air as tiny particles of unburnt carbon will, at any rate, be consumed. The science of burning any fuel is much more complicated than most people imagine, and in the present work it has only been possible to scratch the surface of the subject. If a comprehensive treatise on combustion had been attempted, it would have been necessary to lead the reader into a maze of chemical detail concerning the constitution of fuels, which would be quite unintelligible to any but students who had specialized in this direction, and which would not give an iota of help to the practical man in charge of a boiler plant. It is, however, a comparatively simple matter to explain the conditions that must be fulfilled to secure efficiency, and a brief indication of the nature of these was given in Chapter II. when explaining the methods of burning different fuels to obtain as perfect a combustion as the ordinary fire grate will permit.

The first need is for an intensive educational campaign. Far too many factory owners still consider that the prevention of smoke is a niggling refinement. They care nothing for the pollution of the atmosphere or the resulting damage to health and property, to say nothing of the inconvenience and discomfort caused to the general public. They feel that the advocates of smoke abatement wish to place restrictions upon them for similar reasons to those which led to the requirement that motor-driven vehicles be fitted with silencers to prevent the deafening roar of the exhaust gases leaving the cylinders from drowning every other sound. Some of the objectors go so far as to imply that as the silencer on the motor car certainly does not increase its efficiency, the prevention of smoke will probably affect injuriously the working of their boilers.

It is therefore most encouraging to note that early this year the Universities of Sheffield and Leeds published the prospectus of a series of lectures to be given under their auspices on the subject, and that at the same time a large number of meetings were held in the large manufacturing cities. These meetings proved such a success that similar gatherings are now being arranged all over the country. As proof of the interest taken, it need only be said that in those cases where a small fee is charged, factory employees are paying the fee themselves, and that the men, although tired after a hard day's work, come tramping in from miles round to attend. So remarkable has been the effect of giving proper instruction to those who burn fuel that the Admiralty has ordered special courses of lectures to be given at depots where stoker ratings are trained for service on board H.M. ships.

The blame for the unsatisfactory conditions that have so long been tolerated cannot be laid at the door of any particular person or group. The firemen quite justly say that they have never had the opportunity to learn, but have had to teach themselves, picking up such rule-of-thumb methods as their seniors thought fit to tell them. On the other hand, those employees who are masters of their own craft, and are not supposed to know anything about the scientific production of steam, defend themselves with equal justice by saying that the number of skilled firemen is so absurdly small that the demand is out of all proportion to the supply.

Considerable controversy is going on at present concerning a Smoke Abatement Bill which the Government has promised, through Lord Onslow, to introduce into the House of Lords. Although such a Bill is very necessary, because the damage wrought by smoke is immense, and has a most serious effect on the life of the people, especially in our large towns, it is absolutely imperative that the Bill should not impose further burdens on British industry in its already precarious condition. The crucial question will be the method of punishing offenders. In this connection it seems futile to fine boiler plant owners for making smoke when neither they, nor their employees, know how to prevent its formation. There would be just as much sense in beating a dumb animal the day after it has committed an offence, when it does not understand why it is suddenly being thrashed. The best way of tackling the problem would, in the writer's judgment, be to require every mechanic who is in charge of a boiler plant with an evaporation not exceeding that of six Lancashire boilers, or about 50,000 pounds of steam per hour, to be in possession of a second-class certificate of competency issued by the Government. Every plant of higher evaporation should be in charge of an engineer holding a first-class certificate.

The conditions under which such certificates would be issued might require the applicant to prove that he is a fit and proper person to take charge of a boiler plant, and that he has had at least five years' experience in the case of an applicant for a second-class certificate, and seven years in the case of a first-class certificate, such experience to be gained whilst attending to boilers

A firm violating the law and polluting the atmosphere with black smoke would be first warned by the authorities. In the case of a second offence, it would be cautioned, and should the offence be permitted a third time, a fine would be imposed on the firm, and the certificate of the mechanic or engineer, as the case might be, endorsed. A man who had had his certificate endorsed would not easily find employment elsewhere, and such regulations would therefore make him all the more careful.

It may be argued that it is the fireman who is the person responsible, and not the mechanic or the engineer, and this is literally true, but if a fireman knows that the person in charge takes a keen interest in the way in which he works his fires, and if there is no excuse for making smoke, because the fireman has been taught how to avoid so doing, he will realize that if the firm is fined, and the engineer or mechanic has his certificate endorsed, there will be radical changes, affecting himself, in the boiler-house staff

Fuel will be burnt economically only by men who have been instructed how this can be done. So very few firemen understand their work that courses of instruction are evidently the first step towards solving the problems of inefficiency and smoke abatement. It must be clearly understood that if a fireman works his furnace in such a manner that the fuel is properly burnt, there will be no black smoke. To legislate against the smoke nuisance, without providing for the necessary education of the firemen, is simply putting the cart before the horse.

In the colonies, it may be mentioned, the regulations in force require that every man who is in charge of machinery shall be in possession of a certificate issued by the State authorities.

One other point requires consideration in this connection viz., the impossibility of preventing smoke entirely on some plants because of faulty design Conditions may be so bad that even skilled firing cannot avoid the formation of smoke. It is obviously unfair to punish an engineer or a mechanic who has to work a "wreck of a boiler plant," the owner of which fervently hopes that it will hold together for yet another day. These plants are, of course, in the minority, and the owners are the only persons who ought to be punished for working plants which are a nuisance and a danger to all who live near or work about them. It should not be beyond the power of parliamentary draughtsmen to formulate legislation which will strike at this class of owner without injuring others who are doing their level best to work their boilers properly.

Lest it should be supposed that industrial boilers are responsible for all the smoke, reference must be made, before leaving the subject of smoke abatement, to the iron and steel industry, and to domestic chimneys.

Conditions in the iron and steel industry are totally different from those in any other branch of production, and although the fundamental laws of combustion hold good in this case as elsewhere, the processes are often of such a character that ideal conditions, from the point of view of the smoke abatement enthusiast, are very hard to obtain in practice without undue sacrifice of the quality of the resulting metal. Any modifications that may become necessary to meet the requirements of new legislation will doubtless be introduced with the alacrity and ingenuity which characterize the members of this very ancient industry.

There remains the problem of domestic smoke abatement. As it is out of the question to educate the lay mind to overcome the difficulty of preventing smoke when burning raw coal in the primitive grates that are fitted in most houses, the only alternative is to supply fuel which cannot produce smoke—viz. coke. The ingredients necessary for making smoke have been removed from coke during its manufacture, and it may therefore safely be entrusted to the ordinary person for burning.

Closely associated with the burning of coke is the whole question of national economy, and the preservation of our coalfields. On account of its excellence British coal is used all over the world, and there are few railways, especially on the Continent of Europe, which are not dependent in some degree on the regular supply from this country. Even during the present industrial crisis, which is not limited to a few countries, but is felt everywhere, the export of British coal continues in vast quantities. This shows that, whatever may happen, Great Britain can be sure of a certain export trade in this respect, and the supplies of best coal must be jealously guarded, so that they may for many years to come form the basis of an advantageous foreign trade. All such fuel—other than what is exported—as is suitable for gas making must be subjected to preliminary treatment—for example, low-temperature carbonization or coking such as takes place in modern gasworks The valuable by-products will help to lessen the extent to which British industries are dependent on foreign sources for mineral oils, artificial manure, tar, etc., and the coke will all be consumed for industrial and domestic purposes.

Small fuel, in large variety, will continue to be burnt under industrial boilers, either in specially designed hand-fired furnaces and on mechanical stokers as is customary at the present time, or in pulverized form, or after its conversion into producer gas.

While on the subject of conserving the deposits of coal, it is of interest to know that this is already taking place on a small scale, in so far as colliery owners represent the class of industrialists most interested in fuel economy and the scientific control of boiler plants. The wholesale waste that goes on to-day will not be tolerated much longer, and the partial modification of raw coal before it is consumed under industrial boilers is one of the problems which will have to be solved. A modified fuel which has been given the name of "coalite," and which consists of coal from which some of the by-products have been extracted, is already on the market, but the modified fuel industry is as yet in its infancy. Much research and experiment will be necessary before a hard, smokeless fuel of this character can be made available at a low price.

It seems fairly evident that when the large factory owners who set the price of commodities have realized the saving to be obtained by running their power plants on a modern system of scientific control, the owners of all boiler plants engaged in

the same industries will have to consider the same question. Otherwise they will be unable to offer their manufactured articles at competitive prices.

Happily there are signs that both the daily and the technical press are beginning to see that the time is ripe for instituting a new standard of efficiency. Such well-known journals as *Engineering*, *The Colliery Guardian*, *The Electrical Review*, and *The Engineer*, all of which are interested in the developments which take place in the enormous field known as engineering, never fail to keep their readers informed about the very latest progress in fuel economy, whilst such journals as *The Fuel Economy Review* and *The Power User* devote the greater part of their space to this all-important subject. *The Times* and *The Daily Telegraph* already print articles by the leading authorities on fuel economy, because they realize that it is not only the technical engineer who is interested, but the public in general.

In a sense it is the interest shown by the daily press which is most significant for the future. The city magnate has no time to study technical journals, but a leading article in his morning paper will probably arouse him to the extent of causing enquiries to be made about the efficiency of power plants working in factories in which he is interested. Various classes of people need educating in this matter, and noteworthy improvement can only be hoped for when the problem of smoke abatement is taken up on every side, one section of the community goading on another, until conditions prevail which are more in keeping with the advance of civilization.

The design of boilers has changed very little during the last few years, but there is every indication that considerable developments may be expected in the future. Boilers working at 1,000 pounds pressure per square inch are now being designed, and great strides have been made with pulverized fuel. It is impossible to say how far such new apparatus will affect industry as a whole, because it is one thing to build a special plant and operate it through a highly trained staff, and another to introduce unfamiliar machinery in place of apparatus that has stood the test of years.

The use of pulverized fuel has made rapid progress in America, and there seems no reason why it should not be tried in this country There are British firms which can make the apparatus required, and there are men who can adapt themselves to new conditions, just as happened when staffs first had to be found to run steam turbines and Diesel engines.

For the next few years, however, industry will be supplied with steam from the existing boiler houses, and little change need be anticipated in the boiler house attached to the average factory. It is by more economical working of this much-despised plant that the productive efficiency of factories is going to be greatly improved in the coming days. Rome was not built in a day, and the boiler houses of Great Britain cannot be reorganized with a flourish of the pen, but hard work, constant application, and an iron will to pull the business of steam production out of the rut in which it has stuck for many years will slowly bring about a change.

The educational beginning which has already been made needs to be supplemented by the building up of an organization capable of meeting the new demands. This task also will take time. Certain immediate improvements in power production will be determined upon, and a few employees will be given the responsibility for putting these into effect and seeing that the new standards of efficiency are maintained. A start once made, the circumstances of each plant will determine the future development of the scheme. In the course of time there will grow up a fully equipped department employing the necessary specialists to supervise not only the production of power, but its utilization throughout the factory. Thus, in addition to the boiler specialist, there may be an electrician who will be responsible for the electrical power from the generating station to the apparatus in which it is used; a mechanical expert who will have under his care all the engines, turbines, and mechanical appliances; and a chemist in charge of the laboratory.

Factory owners experimenting in this direction will be wise not to acquire forthwith a large stock of complicated instruments which by their mere presence in the boiler house may create a false impression of efficiency. As was pointed out in an earlier chapter, such instruments are only of service when there is a competent and well-organized staff available to see that they are kept in good working order, and to tabulate and analyze the readings obtained. It may, however, not be amiss at this point again to draw attention to the remarkable progress that is being made in the production of *recording* instruments as distinct from those which merely indicate conditions. Whenever there is a choice, preference should be given to the recording type.

Room must be found in this concluding chapter for reference to a few of the very latest developments in apparatus designed to promote economy and efficiency in power production. Such machinery is shown in figs. 246 and 247.

The study of the efficient utilization of low-grade fuels has not been confined to shore practice. Various firms have endeavoured from time to time to perfect a mechanical stoker for use on board ship. As mentioned in Chapter I., the marine engineer is called upon to burn fuels of a widely differing character, and as mechanical stokers are generally designed to burn a certain class of fuel, the adoption of mechanical stokers on board ship presents some novel problems. Chief among these is the setting of the brick arches which play a very important part in the economical utilization of the fuel. A stoker which has no arches, therefore, seems to lend itself to marine work, and the illustrations show a complete mechanical coal-handling plant supplying fuel to the Erith-Roe self-cleaning underfeed stokers with archless furnaces working under water-tube boilers. The problem of mechanical stoking as applied to marine work has not yet been completely solved, but for large shipping companies working their own coalmines, especially where these yield coal of a poor quality, this question is full of interest, for Oriental stokers will not always work for the wages they are willing to accept to-day.

Of quite a different character is the Howden-Ljungström Patent Air Preheater, illustrated in fig. 248.

The purpose of the air preheater is to utilize the heat of escaping flue gases to preheat the air supplied to the fires. Metal plate surfaces are carried by rotation

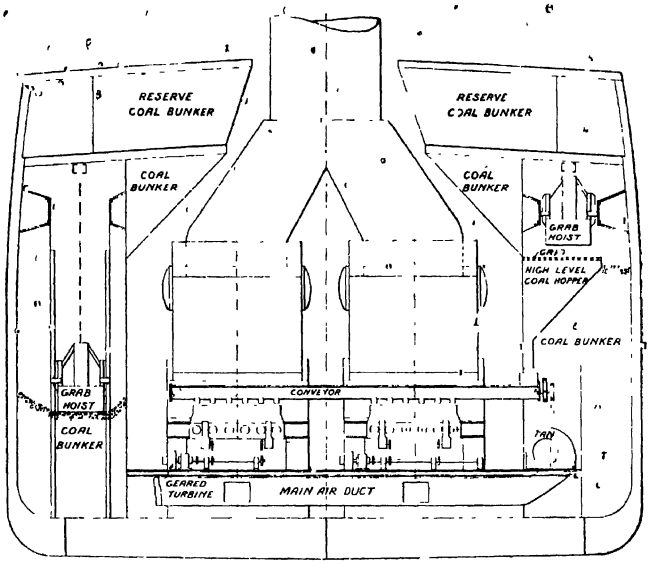


FIG. 246.—AUTOMATIC COAL-HANDLING PLANT SERVING MECHANICAL STOKERS AS FITTED TO MARINE BOILERS. CROSS-SECTION OF STOKEHOLD.

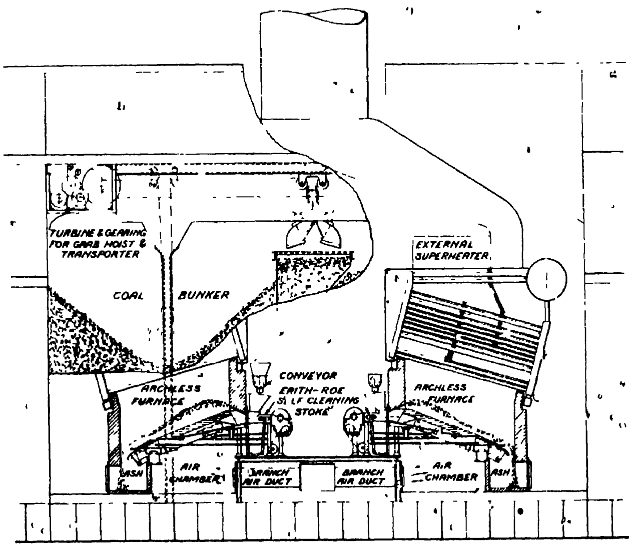


FIG 247.—SAME ARRANGEMENT AS SHOWN IN FIG. 246. FORE-AND-AFT SECTION.

alternately into the currents of waste gases and of cold air. The theory is that in one part of the apparatus the gases give up their heat to the plates, and in another part the plates give up to the air the heat absorbed from the gases.

This apparatus has been invented to meet the needs of plants in which steam is generated at extremely high pressures. For reasons already fully discussed, much uneasiness is felt concerning the possible behaviour of steel economizers under such conditions, and cast-iron apparatus is out of the question. It has therefore become the practice to bleed the turbines for the purpose of heating the feed water, and the question has arisen, What use can be made of the heat in the flue gases formerly employed in the economizer?[1] The air preheater is the only answer yet evolved. It is still in the experimental stage, and its records of performance under actual working conditions in British industrial plants are yet to make.

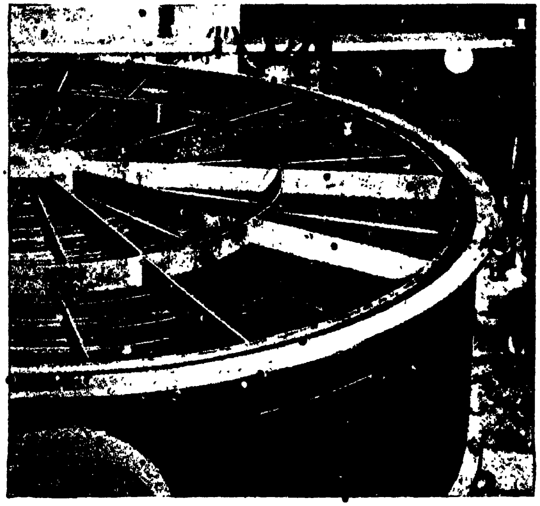


FIG. 248.—HEATING ELEMENTS OF THE HOWDEN-LJUNGSTRÖM AIR PREHEATER.

The Gordon-Lassen Patent Venetian Blind Damper, illustrated in figs. 249 and 250, is one of the last words in damper construction.

It consists of a heavy framework built into the brickwork and finished off flush with the top of the flue. There is no leakage of cold air into the flue, the regulation being carried out by means of a vertical rod about 1 inch in diameter passing through and fitting almost flush with a hole drilled in the top of the framework. Inside the frame a number of movable cast-iron shutters or blinds are arranged, and are of such a construction that they do not warp or twist even in high temperatures.

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[1] "Effect of Feed Water Heating on Plant Economy," *Journ. Am. Soc. Mech. Eng.*, July, 1923.

The position of the shutters is regulated by means of a vertical control rod, so that the damper can instantly be adjusted to any position required. The damper is balanced in such a manner that the operating power required is practically negligible - about ½ pound will move the damper. It is made for hand control, automatic control by steam pressure, or distant control by electric motor, and it may be either vertical or horizontal.

Fig. 250 shows how steam pressure is used for regulating the position of the damper shutters in such a manner as to keep the steam pressure constant. The steam-pressure type consists of a diaphragm, on one side of which water is acting under pressure from the steam main, on the other side, the head of mercury corresponds to the pressure required for the steam. As the diaphragm moves up or down a lever arrangement actuates the damper rod, and in this way a perfectly steady steam pressure is maintained without constant regulation of the dampers by hand.

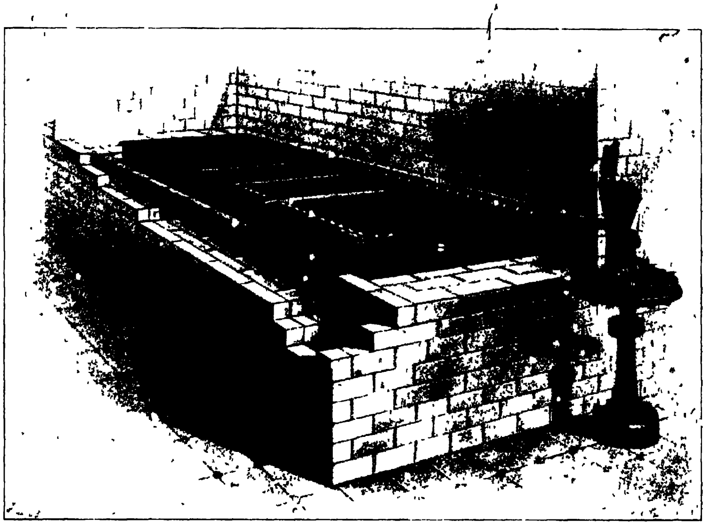

FIG. 249.—GORDON-LASSEN HORIZONTAL DAMPER, COMPLETE WITH REGULATOR.

In view of the stress laid by the author upon the extreme importance of mass and disposition of brickwork in marine boilers,[1] particular interest attaches to two inventions lately made by Mr. Anders Strommen of Trondhjem.[2] One of these inventions consists in mounting an auxiliary firebridge at a certain distance in front of the old firebridge, covering the part of the grate between the firebridges with brickwork or sheet metal, and supplying combustion air in an upwardly directed current through openings in a horizontal covering plate extending rearwards from the top of the old firebridge. The other consists in mounting the firebridge a considerable distance in front of the rear end of the furnace, whereby the grate surface is shortened and at the same time the rear part of the furnace is partially shut off by means of a baffle wall extending downwards from the top of the furnace shell to within a certain distance of the bottom thereof, by which means the combustion products are deflected downwards before leaving the furnace. Very large economies are claimed in experimental tests with the new devices.

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[1] *The Flow of Gases in Furnaces*, Groume Gryimailo, with Appendix by A. P. Williams.

[2] *Marine Engineering*, New York, Aug., 1923.

Professor W. A. Bone is responsible for the invention of a surface combustion method of utilizing producer gas for heating boilers. Tubes filled with refractory material run through the boilers designed for working on this system, and an explosive mixture of gas and air is fed to these at a rate greater than that at which explosion travels backwards in the mixture. The mixture impinging upon an incandescent surface generates a large amount of heat without flame. This heat is transferred by radiation to the water surrounding the tubes. The tubes used are about 3 feet long, and it is claimed that, notwithstanding the intense heat developed within the tubes, the temperature of the exit gases is only about 200° C. Over 92 per cent. of the calorific value of the fuel is stated to be utilized for heating purposes. Existing boilers cannot be adapted to the new process, and it is as yet too early to estimate its possibilities of usefulness under normal working conditions.

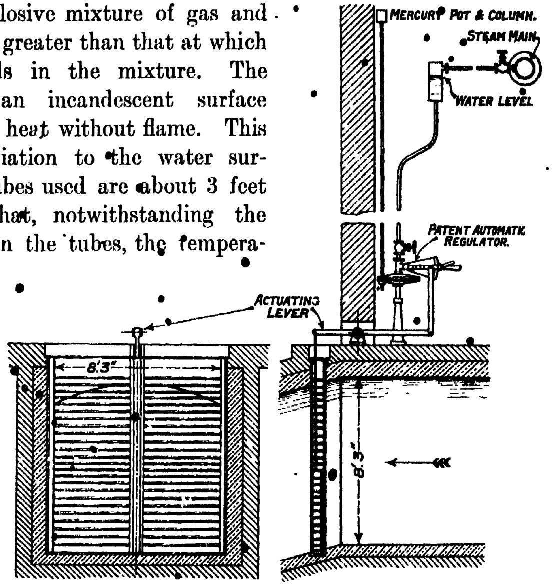

FIG. 250.—VENETIAN BLIND DAMPER ARRANGED FOR STEAM PRESSURE CONTROL.

In his final paragraph the author wishes to re-emphasize the social significance of the methods of control which have been advocated in the preceding pages. Firstly, then, he is convinced that the universal application of scientific management to steam production would effect substantial reductions in manufacturing costs, and thus assist the revival of trade. Secondly, the systematic allocation and utilization of various grades of coal for the purposes to which they are best suited would have beneficial results of a far-reaching character. Much of the best coal would be reserved for profitable export. By-products which are now wasted would be extracted from coal, and the coke remaining after the volatile products had been removed would be extensively used in industry and the home, where raw coal is now consumed. By utilizing the by-products of her coal, Great Britain would become practically self-supporting in the vitally important matters of oil and fertilizer supplies, and would at the same time make an end of the smoke nuisance, which has hitherto had such injurious effects upon the health of British town dwellers. There would still remain a large quantity of low-grade coal, but this could be burnt efficiently by means of mechanical stokers, or in pulverized form. For which reasons it is not unfair to claim that the exponent of scientific methods of boiler management does not simply perform a technical service in industry, but engages in an educational activity fraught with important consequences, both immediate and remote, to the welfare of the British people.

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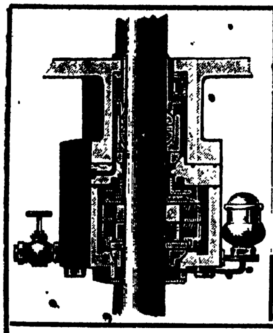

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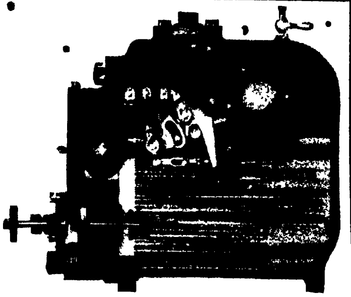

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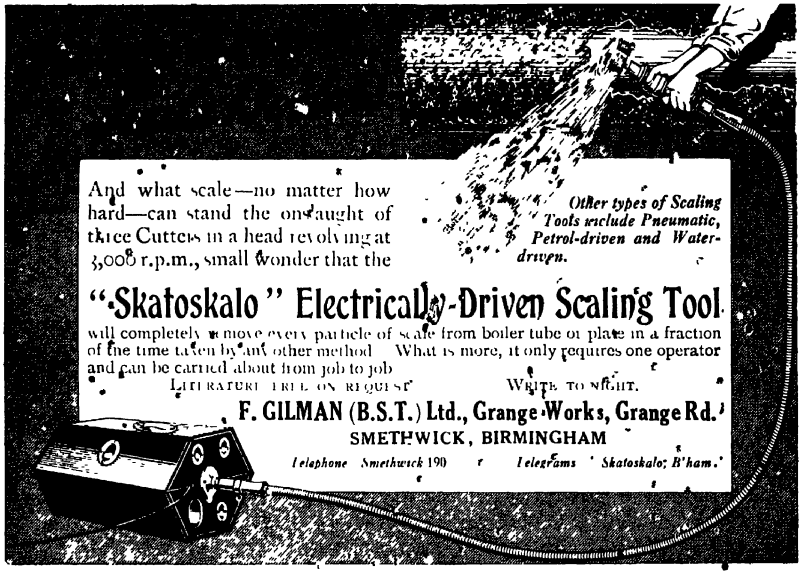

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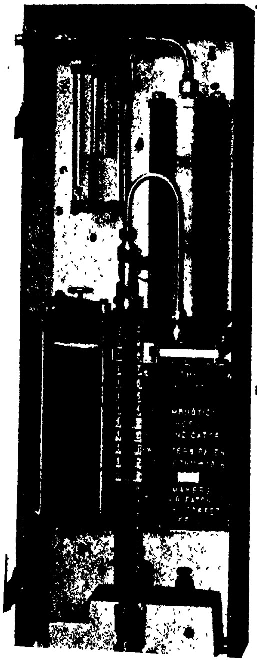

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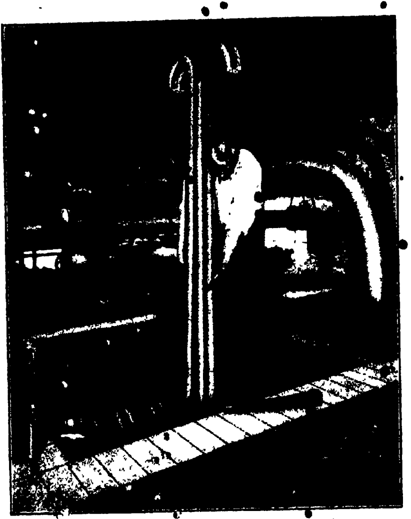

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